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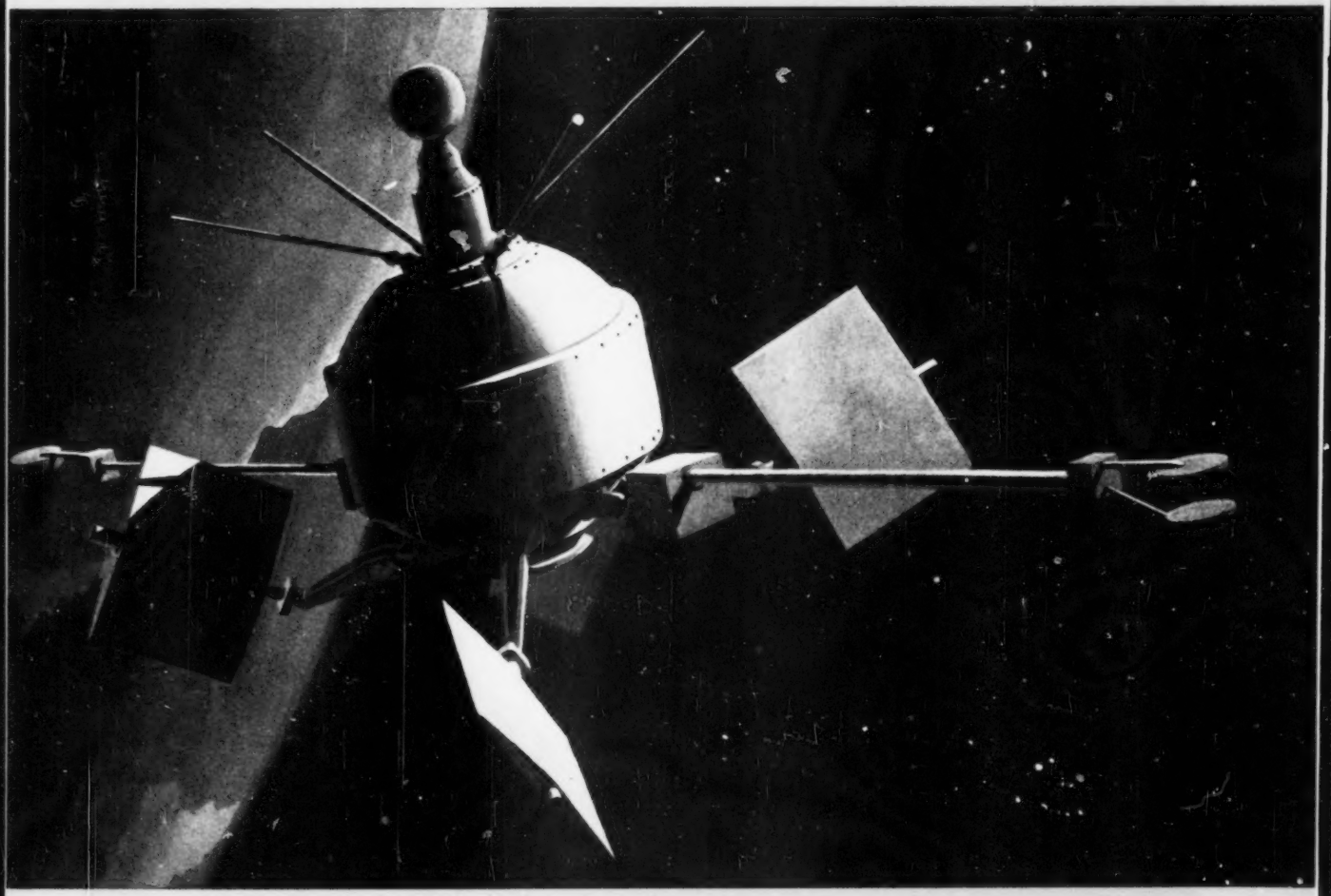

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AEROSPACE

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SPACEFLIGHT

Volume III March 1961 Number 2

THE MAGAZINE OF AEROSPACE SCIENCE AND TECHNOLOGY

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COVER:

Provisional artist's impression of the first U.K./U.S. satellite S-51 for which British universities are supplying some 20 lb. of research instrumentation. It is scheduled to be launched into an orbit inclined at about 50° to the equator from the N.A.S.A. launch facility at Wallops Island, Virginia, by the end of the year. Launching vehicle will be the four-stage, all-solid, Chance Vought Scout.

The European Launcher

On 30 January, representatives of twelve nations met in Strasbourg to discuss political, technical and commercial issues arising from the proposed development of the de Havilland Blue Streak as the basis of a European heavy satellite launcher. To bring this historic meeting about, Mr. Peter Thorneycroft, Minister of Aviation, has travelled widely—first to Australia, Canada, and France, and more recently to West Germany, Norway, Sweden, Denmark, Italy and Switzerland.

The interest which France, in particular, has shown in this venture has been encouraging; and it seems certain that if the project becomes a reality Blue Streak will go into space with a second stage "based on French development work". Early reports that this vehicle will be a Véronique can be discounted. With an initial thrust of only about 8820 lb. (as against some 16,400 lb. of our own Black Knight), the French rocket would be incompatible with Blue Streak in this rôle.

It may be noted, however, that the French are engaged in the early development of an I.R.B.M., and that larger motors of both the liquid and solid variety are being developed. This work is being co-ordinated by the *ad hoc* consortium known as S.E.R.E.B. (Societe d'Etudes et de Realisation d'Engins Ballistiques), comprising both Government establishments and industry. Closely associated is the private company of S.E.P.R. (Societe d'Etude de la Propulsion par Reaction) which has not only done important work with solids, looking into such aspects as light motor cases, case-bonded propellents, swivelling motors, and thrust termination devices, but has acquired considerable experience with WFNA* rocket motors. Eight different types of aircraft have been powered by S.E.P.R. motors since World War II, with more than 4500 firings achieved in flight. In ground test work an average of 2500 tons of WFNA has been consumed a year. Research study has also been made into the use of oxygen, flourine, hydrazine, dimethylhydrazine, and hydrogen.

From this, it can be appreciated that France is far from inactive in the field of rocket technology. But although Britain and France would have the lion's share of the vehicle development, other nations would have important parts to play. These may be expected to extend from the development and manufacture of equipment and individual components for the launcher and its various payloads (both scientific and commercial), to tracking and data acquisition equipment, and additional base facilities at Woomera. Needless to add, co-ordination of the joint effort would be a major problem, but one that can be solved by having management centres divided between Britain, the Continent, and Australia.

It is against this background of interest that between 26 and 28 June, the British Interplanetary Society will be convening in London the first European Symposium on Space Technology. The purpose of this meeting is to bring together engineers and scientists from Western Europe to discuss the detailed problems of joint activity in space research and technology, following closely upon the lines originally suggested in the Society's recommendations to the U.K. Government early last year.

The conference will be open to participation by all countries in Western Europe, and it is also anticipated that Australia and Canada will be represented. It will have heavy industrial overtones and will discuss the most fruitful lines of approach, bearing in mind the resources in men, money and materials, available to participating nations. We are sure that the outcome will be of great practical benefit to all concerned.—K. W. G.

*WFNA — *white fuming nitric acid, used by S.E.P.R. in combination with the fuels, furaline (mixture of furfuryl alcohol and xylidine), or TX (triethylamine and xylidine), or JP4.*

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Surface Exploration of the Moon*

By PETER A. E. STEWART†

The Moon is our nearest neighbour in space and will be the goal of the first expeditions to leave the Earth At the present rate of scientific development, the first large lunar expedition could be mounted in 10 years. This paper outlines such a 10-year programme, examines the problems and some possible solutions and analyses a sample expedition.

MAP OF PRINCIPAL FEATURES

The Reasons Why

The reasons why we must explore the Moon are many and varied. First there is the mental and physical challenge, then there are the economic factors. If we look back on history, we find that no piece of basic exploration has failed to pay handsome dividends. It is believed that considerable economic gains and fringe benefits will accrue from the exploration and subsequent development of the nearer planets, Mars or Venus.

This work will be facilitated, and the launch vehicles have a greater payload to launch-weight ratio, if they are constructed and fired from a site in vacuum and having low gravity.

Geologically, we may learn a tremendous amount from a surface exploration of the Moon, which was formed with the Earth about 4–5 billion years ago. Since that date, it has remained unchanged by surface erosion and is a geological museum where *lunalogists* and *lunagraphers* will learn more of the processes of planetary formation. I use the words "lunalogist" and "lunagrapher" as a counterpart to "Geologist" and "geographer" in place of the unwieldy "senenologist" and "selenographer" in the hope that they will find a wider useage.

Lunalogists would wish to examine crater types, rills, rays, maria and surface dust and attempt to correlate lunar and Earth rocks. A study of the lunar rock structure and the sub-surface contours of maria and craters could only be carried out by a programme of seismic shooting or resistivity testing on the lunar surface by a human team. Vulcanologists would welcome the opportunity to examine the lunar craters and compare their dynamics with those of Earth and assess to what extent meteoroid bombardment has been responsible for lunar topography.

Biologists, in a search for anaerobic life on the Moon, would be investigating the existence of other life in the solar system.

Once a lunar landing were successfully achieved, the door would be open for other sciences to initiate work programmes.

Due to its vacuum, the Moon would make an ideal astronomical observatory, free from the limitations and complexities of the already obsolescent concept of the satellite observatory. All the sciences and possibily later some industries demanding vacuum conditions could be lunar based. Physical laboratories would freely be able to study the behaviour of cosmic rays and other nuclear particles.

The study of human engineering will benefit from experiments on heart and blood circulation system performance under reduced gravity conditions. This research may assist in prolonged exposure to zero gravity conditions or geriatric studies.

With an eye to the future, early objectives in lunar exploration will be the evaluation of lava domes as "chez nous" for later exploration teams and prospecting for oxygen bearing rocks.

These, then, are some of the reasons why we shall go.

* *Paper presented at a meeting of the British Interplanetary Society in London on 17 September, 1960.*

† *Astronautics Section, Advanced Projects Group, Hawker Siddeley Aviation Ltd.*

The Moon—Physical and Lunagraphical Data

Physical Data

The Moon has a diameter of 2160 miles and has a mean distance from the Earth of 238,900 miles travelling in an elliptical orbit.

It is more correct to describe the Earth-Moon system as a double planet pair rather than a primary and a satellite, the barycentre or centre of revolution of which lies 1022 miles below the surface of the Earth.

The main body of lunar data may be found in ref. 1, with a selection of the principal facts in Fig. 1. A good exposition of the radio-activity standards may be obtained from ref. 2.

One of the most important facts is that lunar gravity is about one-sixth of Earth's gravity.

Incident Radiation

The principal radiations are cosmic radiation, background radio-activity, corpuscular radiation and non-corpuscular radiation from the Sun.

The cosmic radiation is not excessive, but the aftermath of solar flares results in a flow of non-corpuscular radiations such as X-rays and corpuscular radiations such as high energy protons. At times the solar flare dose rate rises to 40 rem./hr., whereas the safe dosage is in the order of 0·3–0·5 rem./wk. This corresponds to a radiation level of 1000 roentgens/hr. with particle energies in the hundreds of MeV. ranges. Solar heat on the surface is 80·6 B.Th.U./ft.²/hr. and the resulting isothermal lines can be seen in Fig. 1.

Due to the inclination of the lunar orbit, the thermal equator varies by $\pm 6°$ with respect to the physical equator.

Environment

The Moon's magnetic field has been assessed in the order of $1{\cdot}4 \times 10^{-6}$ gauss, but the Soviet Luniks did not register any appreciable field above the background.

However, J.P.L. have suggested that the lunar magnetic field is confined by the solar radiation to a thin layer above the sunlit surface and may extend for a considerable distance on the dark side. A weak magnetic field, however, would agree with theories of a small iron core.

Formation of the Moon

The current theory on the formation of the Moon is due to Weizsacker. A review of lunar formation theories will be found in ref. 3 and an excellent lunalogical survey may be obtained in ref. 4.

Presently it is believed that the Earth and Moon were formed side by side in the same primeval gas cloud at a closer distance than now exists. A solid Moon could not have existed closer than 2·9 Earth radii (11,500 miles)—the Roche limit. It would seem that due to convective flow within the gas cloud, the lighter elements such as the silicates passed to the Moon from the Earth. Thus the silicate/iron ratio of the Earth is low and the Moon is high with respect to average values.

Definition of Lunagraphical Terms

The surface of the Moon is telescopically a mass of detail; however, the principal features fall into well-defined categories. These may be defined as follows:—

Craters

The name "crater" is unfortunate but persists for lack of a suitable alternative. Craters fall into three principal categories:—

(*a*) Walled plains. These are the oldest form of crater and are generally thought to be ring faults with dyke extrusions.

They form the largest craters (Bailly, 183 miles diameter on the southern limb) and the deepest (Newton, with a ring wall of 29,000 ft. elevation). Due to their early formation they have often been ruined by other surface movement or inundated by mare, an example being Stadius.

(*b*) Empty craters. These craters have flat floors and were formed at a later stage in lunar history than the walled plains probably during the reheating and remelting phase. It is probable that they are the remnants of burst lava bubbles or domes.

(*c*) Craters with central elevations. The central elevation may vary from hummocks to large peaks as in the case of Aristarchus and were probably magmatic extrusions from a central vent.

(*d*) Rows of small craters. These are caused by extruded magma or lava along lines of faulting.

Drowned Structures

Are lunalogical features, walled plains, mountain chains, etc., which have been inundated with maria lava flows of later date than their own formation.

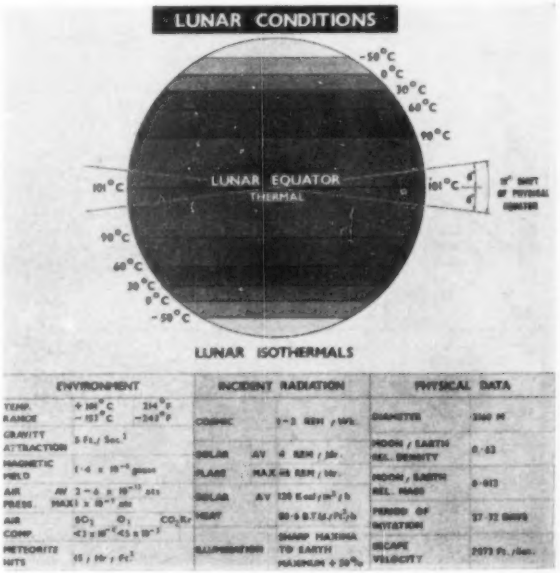


Fig. 1.

Faults

As on Earth are fractures of the lunar crust in which one side has been displaced vertically with respect to the other. A classic example is the "straight wall," a fault of 60 miles length and 800 ft. height, lying in the Mare Nubium in the south-east quadrant of the Moon.

Graben

Are depressed areas between two adjacent fault planes, an example of which may be the Alpine Valley.

Isolated Mountains

Were formed when the mountain chain of which they are the topmost peaks was submerged or alternatively are large pieces of crustal material ejected by meteoric impacts. Examples are Pico and Piton in the Mare Imbrium.

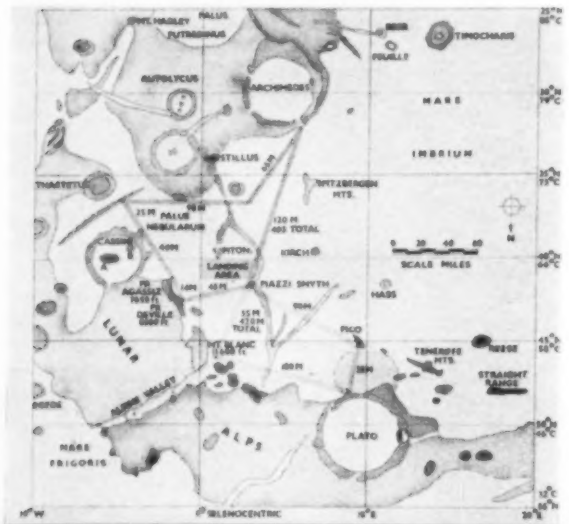
Lava Domes

These appear to have been formed as bubbles of gas from the Moon's interior which were generated when it was at high temperature and did not burst, but solidified. There are often small craters on the dome crests. Examples are the field of lava domes near the crater Marius.

It has been suggested that these are capable of conversion into living quarters at a later stage in lunar exploration.

Lunabase Material

This is a name given by J. E. Spurr an American Geologist and lunalogist to the dark mare material which can also be described as lava, magma or ultrabasic material. Due to the meteoric impacts, splashes of this material are found in the lighter coloured uplands.



MERCATOR PROJECTION OF MARE IMBRIUM AREA

FIG. 2.

Lunarite Material

Is Spurr's name for the upland or terrae features of lighter colour. This is the crustal material of the Moon which was formed during the original heating process. Recent work in Russia suggests this is a igneous rock of gabbro type and may indeed be similar to quartz, possibly formed in the original gas cloud and entrapping gas.

Maria

Are outflowings of lava or lunabase material which occurred during the second melting phase and was contemporaneous with some of the larger meteoric impacts. This may have occurred after the formative gas cloud dispersed and allowed higher velocity meteors to impact. A prime example is the Mare Imbrium.

Rays

Usually emanate from craters and are thought to be either due to volcanic ash or the matter thrown out by meteoric impact. These could indeed have been produced by impact when the original gas cloud was present and the ash would be lunarite material. The principal example of a ray system is Tycho.

Ridges

Occur mostly in the Mare area and are compression pressure ridges caused by the contraction of the lunar surface crust. In some cases, the ridges have split along the crests and lunabase or lunarite material has been revealed. This may be explained by dike extrusions or the contraction of lunabase material from lightly covered drowned structures.

Rills

Are clefts on the lunar surface of varying lengths and fall broadly into three main divisions:—

(*a*) Rills on maria and flooded craters which are caused by tension cracks as in some ridges and are usually irregular in shape.

(*b*) Rills of regular shape with brilliant white walls of lunarite material such as the Hyginus and Ariadaeus clefts.

(*c*) Broad and shallow rills often confused with Graben.

Terrae

The opposite of Mare and is the collective name given to surface features such as mountain ranges and rocks not covered by Mare lava flow.

A detailed description of the lunar surface will not be given here but may be seen in refs. 5 and 6.

Factors Affecting Surface Formations on the Moon

It would seem that the Moon formed originally in the enveloping gas cloud and commenced its first cooling process. During this process large lava domes were formed often along lines of weakness such as the Ptolemaeus, Alphonsus, Azarchiel, Purbeck, Walter, Clavius line of craters. Subsequently the Moon entered a second stage of contraction or heated up due to radio activity in the core. At this stage there were some extremely large meteoric impacts such as those occurring in the Mare Imbrium, Archimedes (immediately post-mare formation) and later in time Aristillus, Eratosthenes and Copernicus.

The Mare Imbrium impacts occurred when magma was commencing to flow from cracks in pressure ridges and beginning to form the maria themselves. Subsequent faulting from internal pressures or tension caused the rills and fault development and local escapes of magma formed the later phase crater development. Finally, small volcanoes such as Timocharis appeared on the scene. Indeed recently volcanic activity was observed below the South peak of the crater Alphonsus by the Russians and spectrograms of carbon gases were obtained.

Nature of the Lunar Surface

It has been suggested by Gold and others that a layer of dust covers the lunar surface—in some cases exaggerated figures have been ascribed to this thickness. However, radar measurements have assessed the thickness at varying figures and it may be that local drifts have occurred due to exfoliation in the same way as scree slopes. The lava on the mare may be covered for about 6 in. in dust, but it is not likely to be more. Russian scientists Barabashov and Chekirda have carried out photometric, colorimetric and polarimetric analyses and conclude that the surface is covered with disrupted "tuff-like" rocks and scattered large grain volcanic ash.

Other coverings are a porous, striated sponge-like material originating from the solidification of lava similar to gabbro and basalts. The surface rocks have a poor conductivity as was proved during eclipses in 1927 and 1939.

FIG. 3.

In 1927, Pettit and Nicholson found the surface temperature fell by over 250° F. in about an hour by the telescopic use of thermocouples. Confirmation was obtained in the latter year.

Choice of Landing Area on the Lunar Surface

The choice of landing area on the lunar surface depends on a careful analysis of a number of factors. One of the principal criteria is the type of expedition envisaged; for instance, optimum location would probably vary for 100-, 200- and 300-mile operating radius expeditions.

From previously published literature the following table of locations, etc., has been produced:—

** Wilkins suggests several craters as landing points and studied the problem only on the surface condition. He mentioned that any mare was suitable. The craters suggested are: Anaximander, Archimedes, Billy, Condorcet, Endymion, Euler, Grimaldi, Meton, Otto Struve, Plato, Pontecoulant, Ptolemy, Schickard, Schomberger, Stofler, Sinus Medii Vendelinus.*

Year	Writer	Area	Exploring range	Expedition duration
1950	R. E. Heinlein, "Destination Moon"	Harpalus	—	—
1952	E. Burgess	Palus Putredinus	100 miles	14 days
1953	Von Braun Committee	Sinus Roris	250 miles	42 days
1954	A. C. Clarke	Mare Imbrium, 5 miles west of Piton	—	—
1954	H. P. Wilkins	Various*	—	—
1960	Present writer	Mare Imbrium, Piazzi Smyth	250 miles	70 days

Other Criteria

(*a*) For a working expedition, some degree of movement is required and therefore due to its rough terrain, the southern hemisphere has been discarded.

(*b*) In order to allow tolerable working conditions the base should not lie in a high temperature zone but in one of the cooler latitudes. This condition is fulfilled in the choice of Sinus Roris, Harpalus, Mare Frigoris and northern Mare Imbrium.

(*c*) Lunalogical (geological equivalent) factors suggest that the Mare Imbrium area was the scene of one of the basic impacts in lunar history, this in fact caused the formation of the mare.

These factors narrowed the choice down to the Mare Imbrium and a review of the accessible surface features narrowed the area still further to the most central base, this being in the area of Piazzi Smyth. The landing site itself will be the subject of a closer reconnaissance by satellite vehicles, backed up by point landings later in the programme.

The Area of the Mare Imbrium

Fig. 2 shows the Mare Imbrium area which has maximum and minimum temperatures of 85° C. and 32° C. respectively. A brief note of the principal features follows:

(*a*) Plato (crater): this is one of the outstanding features on the northern Imbrium shore and is a large crater of early date over 60 miles in diameter. The ring wall has an average height of 3500 ft. with peaks up to 7000 ft. in height. It is accessible from the Imbrium plain by a valley at the south-east. The floor has appeared to show signs of change, and is of a dark lunabase material.

This could be an expedition objective.

(*b*) Lunar Alps: a range of lunarite mountains with peaks rising to 11,800 ft. at Mt. Blanc with other peaks at lower altitudes. This is split by the:

(*c*) Alpine Valley: of length 80 miles, it is a great gorge cutting through the Alps and probably formed at the time of the Imbrium impact. The method of formation of the valley could be an expedition objective.

(*d*) Cassini (crater): lies at the southern tip of the lunar alps and is of interesting and complex structure with a large ring crater of 36 miles diameter encompassing two smaller craters known as Cassini A and Cassini B. The ring wall of Cassini has heights up to 4000 ft. Cassini A is 8 miles in diameter and encloses a smaller crater of white lunarite material and having a central pit, these are known as the "washbowl" and "plughole" respectively. Cassini B is a smaller crater within the ring wall. An investigation of the structure of Cassini could be an expedition objective.

(*e*) Theaetetus: a bright little crater 16 miles in diameter lies north of Cassini and in the intervening ground is a good example of a rill. Examination of the structure of this typical rill would be an expedition objective.

(*f*) Aristillus: is a very good example of a crater with a central mountain. The crater is 35 miles in diameter with terraced walls rising to 11,000 ft. and has a small ray system extending from its walls. The study of this type of crater and ray system would be an expedition objective. This crater lies west of Theaetetus.

(*g*) Archimedes: another crater which lies south-west of Aristillus and is an example of a large fine walled old-type crater 50 miles in diameter. The walls are generally 4000 ft. in elevation with peaks of 7400 ft. This would be a good example to study of this type of crater as an expedition objective.

(*h*) If time permits another feature worthy of study is the volcano Timocharis, the central vent of which is 1 mile in diameter. The crater is 23 miles in diameter and 7000 ft. in height. However, this is not considered a prime objective.

In general, the foregoing features lie in the outer basin of the Mare Imbrium, but an expedition could on a long traverse carry out a programme of seismic shooting to determine the structure of the crustal rocks extending to the inner basin. Other features of interest are:

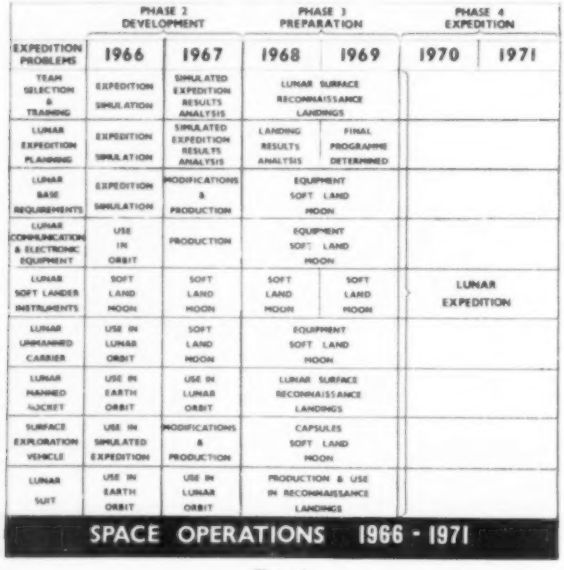


FIG. 4.

(*j*) Piton: a mountain of lunarite material 7000 ft. high with two peaks, one of which has a summit craterlet. This mountain is isolated on the Mare Imbrium.

(*k*) Pico: a similar mountain having three peaks and 8000 ft. in elevation. This concludes the survey on the Mare Imbrium area.

Need for an Integrated Space Programme

At this moment when consideration is being given by H.M. Government to a space programme in conjunction with other countries, one can review the next decade in space and plan an integrated space programme.

The basic and ultimate aim of such a programme would be the landing of sufficient material on the Moon to carry out in 1970–71 an expedition analogous to the trans-Antarctic expedition led by Dr. Fuchs. Utilizing known and tried techniques, a bold decision now could pave the way to a worthwhile contribution to space exploration. Fig. 3 and 4 show the development of a programme for space operations from 1960–70.

Team Selection and Training

The question of personnel selection and training for space flight was exhaustively treated by Brig.-Gen. Flickinger at the Tenth I.A.F. Congress in London (refs. 7 and 8). The requirements for selection are:—

(1) High biological efficiency of the body with no latent defects.

(2) High intelligence.

(3) A stable and compatible psychological personality.

(4) Tolerance to isolation and agrophobia (or intolerance of open spaces).

(5) Physical and psychological endurance.

(6) Resourcefulness and inventiveness.

Training would be carried out by giving the team as a whole experience in performance under hostile environments, *i.e.*, underwater swimming, climbing, cave exploration, and polar travel. Besides giving team experience, this will show up or eliminate personality incompatibilities.

Later the expedition could be simulated in vacuum chambers on Earth and at a site in a desert with full equipment including a modified surface exploration vehicle having higher powered motors. Final stages of training would include orbital flights and short duration reconnaissance landings on the lunar surface at selected points on the expedition route to prove the landing and return flight techniques.

Lunar Expedition Planning

This problem covers the rationalization of the expedition programme. Some types of information are better obtained by automatic probes than by humans and vice versa.

Machines are limited in observational bandwidth and a human observer can often give a wider and more correct appraisal of a situation by the conduct of small auxiliary experiments. A probe will only give data on the expected phenomena for which it is instrumented.

Automatic observers are best for:—

(1) Point measurements from flat surface areas if delivered by rocket.

(2) Point measurements in difficult terrain if placed by humans.

(3) Fixed observations of local conditions over a period of time.

(4) Short radius automatic unmanned expeditions.

Human observers are best for:—

(1) Particular local complex assessments of problems suggested by automatic monitors.

(2) The exploration, area investigation and placement of automatic observers in difficult terrain such as the south of the Moon.

(3) Lunalogical collections and local area interpretations.

(4) Determination of sub-surface lunalogical structures by complex seismic shooting or electrical resistivity methods.

(5) Determination of the nature of rays from craters over long distances, *e.g.*, from Tycho.

(6) Sampling and interpretation of cores from drillings.

During the 1960–65 period the integration of these capabilities will be determined. The expedition will be analysed by operational research and may even be simulated by computers on "games theory." The results of this work will be tested as a simulated expedition at a suitable site and re-evaluated before final work programme determination in conjunction with reconnaissance expedition information.

Another large area of work is the constant rationalization of launch vehicle payloads to ensure transport efficiency.

Lunar Base Design

One of the questions to be determined here is whether the base will be above or below ground. Another choice will be between inflatable structures (ref. 9), payload life compartments or a "hard-top" fabricated structure as described in ref. 10. It has also been suggested that lava domes may be used as bases.

These designs will be evaluated at the desert site during the course of the simulated expedition.

Some of the installations required by a lunar base are given below—a lunar base analysis is made in ref. 11.

Technical and Domestic Installations

(1) Expedition control centre.

(2) Communications and data transmission centre.

(3) Electronic and mechanical workshops and stores.
(4) Electrical, water, air and food supplies.
(5) Vehicle assembly and maintenance workshops.
(6) H.T.P. propellent storage for short range tractors and return vehicles.
(7) Kerosene storage for short-range tractors and return vehicles.
(8) Liquid oxygen storage for air and return vehicles.
(9) Personnel accommodation.
(10 Canteen facilities.
(11) Sick bay.

Design of Lunar Communication and Electronic Equipment

This problem covers the design of communication equipment for data transmission from Earth to Moon, lunar suit transceiver design and the development of relays and beacons to operate reliably over periods of years in hostile environments. The data transmission equipment must be capable of transmission of written data, photographs and line drawings, as weight will be at a premium in return vehicles.

Lunar suit transceiver requirements will be covered later.

Lunar Soft-Lander Payloads

There are a number of problems to overcome in the design of payloads to be soft-landed on the Moon.

The first payloads will be of the hard impact type as put forward for the "Ranger" (N.A.S.A.) programmes. The "Ranger" will have payloads with the protection of crushable structures providing safety up to impacts of 1000 *g* at 300 m.p.h.

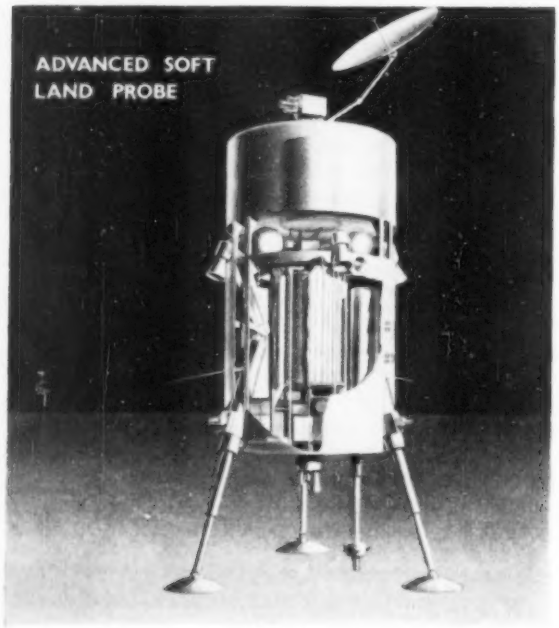


FIG. 5.

Later will come simple instrumented payloads that will teach the techniques of soft landing. These will be followed by more advanced probes of the "Surveyor"—(N.A.S.A.) or "Migrant"—(K. W. Gatland) (ref. 12) type. They will carry out point investigations of the lunar surface in detail.

Finally before the arrival of man, a series of automatic tractors or wheeled vehicles may be put down. These will be capable of carrying out short-range local investigations and are exemplified by the Khlebtsevich "Tankette" (ref. 13) and the N.A.S.A. "Prospector" with an operating radius of 50 miles. The technique of operation of such vehicles is currently being investigated in the U.S. by the development of a tracked vehicle to move at great depth on the sea bed and climb slopes and examine rock structures by the employment of searchlights and television cameras.

Fig. 5 shows a typical advanced soft-land lunar probe: it is 6 ft. in diameter and about 15 ft. in length with landing gear retracted.

Deceleration is supplied by means of four rocket motors using hydrazine hydrate and hydrogen peroxide. An assessment of propulsion requirements for soft lunar landings has been made by Carton of Cranfield.

The programme of operation of this vehicle is as follows.

Separation of the probe from the final stage of the boost vehicle occurs at the end of the launch phase. The probe is mounted in an inverted position on the booster to save fuel for landing but a corrective attitude stabilization pack is attached. This separates before arrival at the Moon.

On arrival the probe decelerates into a circular orbit, and its position is accurately determined from the Earth together with its altitude and period with respect to the landing point on the lunar surface. These data are fed into computers at the Earth control centre and an approach programme fed via radio into the command guidance system in the probe.

The position of the probe relative to the lunar surface meanwhile has been determined with reference to a number of hard impact radio beacons. The location of these beacons will have been previously accurately fixed and those out of position switched off or destroyed.

At the correct time, the Earth-based computer initiates the landing programme and a short burst of rocket thrust modifies the approach path. The probe commences to fall towards the lunar surface in a conic trajectory. Fine correction may be applied by mid-trajectory thrust.

The probe is now falling almost vertically and its attitude relative to the lunar surface will be examined by rotating-scan infra-red sensors, and attitude thrust correction applied. Three radar altimeters, the dishes of which also form landing feet, will compute the altitude from the ground, the rate of change via doppler and also the velocity of approach.

Those in Lunik II operated at 183·6 Mc/s. Just before touchdown a final thrust will kill residual velocity. "Cut-off" will be initiated by the pneumatic shock absorbers breaking a burster disc.

Following "touchdown" a programme will be initiated as follows by means of a clock:—

(1) Background radio-activity will be measured together with magnetic field intensity. This may be measured with either a rubidium vapour magnetometer as used in "Ranger" or a "gate flux" magnetometer as used in Lunik or perhaps a proton resonance magnetometer. The magnetic field will be determined in both horizontal and vertical planes and continuous measurements will be made.

(2) A probe spike will then be lowered to touch the lunar surface and the distance information will be fed to a triple lens turret for fine focussing, attached to a television camera below the vehicle. This will have a normal lens for use during the approach, a wide angle lens for surface use and a long focus microscope of adjustable range for surface examination.

(3) After a time interval a solid rocket motor with tangential nozzles will be fired, this powers a rock drill which buries itself in the lunar surface. The performance of the drill has been previously calibrated and the hardness of the surface rock can then be deduced. The core of the drill carries a thermocouple for rock temperature measurement and a simple carbon button seismometer for geological investigations. Seismometers for such a lunar probe are currently under development at California Institute of Technology.

(4) At the same time as the above, the surface material is also inspected by X-rays. The incident radiation is measured and the reflected rays from the surface are analysed by means of an X-ray spectrometer.

(5) The dish antenna is then erected, to operate later on a frequency of about 1500 Mc/s.

(6) A nuclear thermionic generator then starts up and the power is then fed directly instead of via batteries.

(7) The television camera at the top of the probe scans the sky for the Earth and centralizes the dish antenna. The movement due to Moon libration is then catered for automatically.

(8) The information previously obtained has been stored on magnetic tape, this is then transmitted to Earth by means of the telemetry sender.

(9) A torsion type gravimeter then commences continuous measurements.

(10) Singly, a series of rockets having various impulses are fired from three ports in the side of the vehicle and seismic records are taken by the spike seismometer. The payloads of the rocket contain a Geiger tube, low power single channel transmitter and pivoting shaped charge. Upon impact the radio will be energized and transmit radio-activity information to the probe via the three antennae. After a time interval, the shaped charge will be detonated and the generated pressure wave will be recorded at the seismometer.

(11) The television camera at the top of the probe can commence slowly building a picture either directly or from a photograph of the lunar scene.

(12) One lens of the scanner can be a telescope which can be aimed as required possibly at the Earth, Sun or stars.

(13) Thermal control is obtained by the use of shutters which rotate under the control of bimetallic strips to show areas of increasing or decreasing absorptivity or emissivity depending on the incident radiation and probe temperature.

This completes the brief analysis of the soft land probes which will touch down at points along the proposed route that the overland expedition is to follow, to obtain local information on rock surface conditions, radiation intensities, the plotting of lunar magnetic fields, etc., for the use of the expedition.

Launch Vehicle Development

The current space booster is the "Blue Streak/Black Knight" combination described in ref. 14. The first stage has two Rolls-Royce liquid oxygen/kerosene motors built under licence from N.A.A. Rocketdyne. These motors are similar to those which will power the "Saturn" vehicle and are lineal descendants of the V-2 motor through various uprated versions.

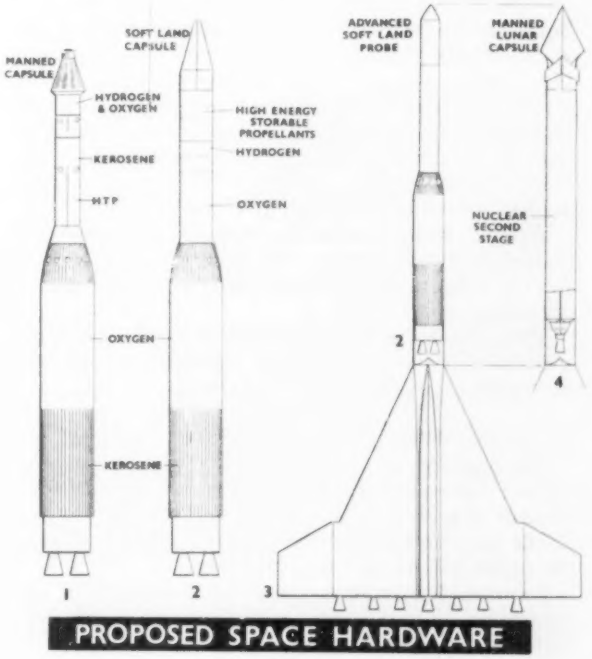


FIG. 6.

The first satellites will probably be for scientific and communications purposes, and it is possible that later an attempt may be made to impact a payload of about 50 lb. on the Moon.

Following the successful proving of the launch vehicle, a high energy third stage using liquid oxygen and liquid hydrogen could be employed, (vehicle 1) Fig. 6. This could give an orbital capability of about 2500 lb. and may be of interest for a manned capsule for the R.A.F.

The next phase in the development of the launch vehicle could be the employment of a high-energy second stage using liquid oxygen and liquid hydrogen with a high energy storable propellent for the third stage. This could possibly place 4000 lb. in a 300-mile orbit and about 450 lb. on the Moon (vehicle 2). Very little work would be required as the motor could be a Pratt and Whitney motor made under licence. This type (vehicle 2) would allow a larger manned capsule and soft-land payloads.

At about this time, the development potential of this vehicle will have been fully realized and it will have been necessary to commence design work on a larger vehicle —this would be a "Saturn" equivalent.

However, the "Saturn" does not have a good recovery system and this vehicle wastage would not be tolerated. The vehicle would therefore be designed to function in the form of a supersonic glider after "burn-out." Eight "Blue Streak" motors would be mounted, two per arm, and a single "Stentor" per arm would be used for control during re-entry. This type of booster would be guided on re-entry and could be recovered by parachute.

The upper stages of such a vehicle (No. 3) would initially be formed of a previous configuration (vehicle 2) but in later development should be nuclear powered with an S.I. of 800–1000 sec. Development could be initiated of a similar design to that proposed by Dr. Wyatt, Hawker Siddeley Nuclear Power Company (ref. 15) using ammonia or hydrogen. This vehicle would in the early part of its life have a heavy orbital capability and with a nuclear second stage (vehicle 4) be capable of soft landing from 5 to 7 tons on the Moon.

Such a programme as this would utilize tried and proven hardware except for the nuclear motor development and the standardization should give a high degree of reliability.

These would be the carrier rockets for the automatic probes, expedition equipment capsules and manned reconnaissance vehicles.

The Lunar Surface Exploration Vehicle

The requirement for design study work on a lunar surface exploration vehicle has been realized now for a number of years.

The first landings will be purely reconnaissance and the rocket will be used as a fixed base.

However, for the lunar expedition itself a vehicle will be required for movement over the surface up to 500 miles and having the capability of supporting life for the crew members.

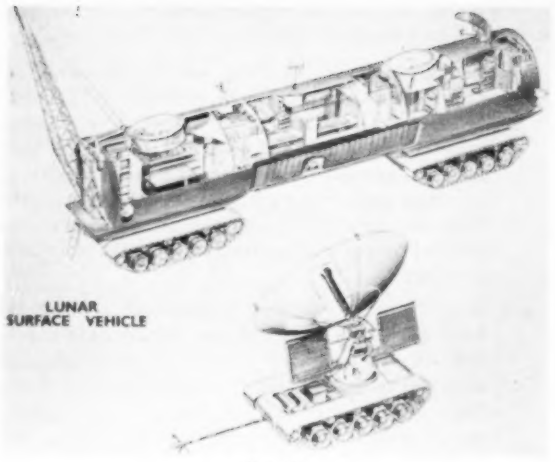


FIG. 7.

A number of proposals have been formulated for lunar vehicles usually of most unusual conception.

(1) During 1953, von Braun in "Man on the Moon" produced drawings of a tracked vehicle driven by hydrogen peroxide exhausting through steam turbines (ref. 16), but the dimensions of the vehicle do not seem compatible with its stated exploring range of 250 miles. However, such short range tractors with cranes will be required in the initial stages of the expedition to collect equipment and capsules from the landing area near Piazzi Smyth.

(2) In 1954, Oberth in "Man into Space" proposed a vehicle and later developed the idea in "The Moon Car" (ref. 17). This vehicle is of radically new design and is powered either by solar energy or a 70 h.p. H.T.P. motor. The vehicle is a unipod stabilized by a large gyroscope and moves about the lunar surface on small tracks, or small wheels, and when it comes to a crevasse hydraulically compresses its pod and then jumps the crevasse.

(3) Tinsley in 1959 (ref. 18) suggested a unique inflatable structure again using gyroscopes for stabilization with a large wheel around the periphery. This vehicle, 32 ft. in height with a crew of five or six, uses solar power.

(4) Another design used large low pressure tyres in the same way as the swamp-crossing vehicles of the southern states of America and yet another took the form of one of the earliest diamond tracked British tanks. This vehicle had tracks in long rigid sections which could cross crevasses and the vehicle itself lay within the tracks.

However, these designs did not draw on previous experience of exploration work in hostile environments such as, for instance, in Antarctica. A logical extension of the principles proven in the

Tucker "Snocat" and the Russian "Kharkovchanka" was thought to be a better approach.

Fig. 7 shows the proposed "lunar surface vehicle"; it is 65 ft. long, 16 ft. 6 in. high and has a crew compartment of 12 ft. diameter. It consists principally of three separate airtight compartments, or capsules, mounted on two bogies and having a power generation trailer.

The total weight on Earth of this vehicle is 81,000 lb. or 36 tons. It is powered by a thermionic converter with a total power output of 350 kW. driving motors of 240 h.p. and the necessary supplies. The vehicle is transported to the lunar surface in seven capsules as the the payload of vehicle 4. It is proposed that two or three such surface vehicles should be used in the lunar surface expedition.

The forward section of capsule "A" contains the control room where the crew on duty work and where the vehicle driver/crevasse bridging crane operator sits in a conning dome. The forward section of capsule "A" contains lunar suit stowage, the middle section the lockers and work tables for the exploration team, and five television displays, the rear section contains the galley, food store and the air conditioning equipment. The segment above the capsule contains water and liquid oxygen and those on either side contain food and oxygen supplies for lunar suit use. This equipment helps to shield against environmental radiation. Air locks at each end produce the separation.

Capsule "B" contains bunks for sleeping nine persons, six per watch and three sick. It also contains personal lockers for use by the crew of twelve.

The rear of capsule "B" contains washing and shower facilities and two toilets. The area above capsule "B" contains liquid oxygen and water. The area below contains 12,400 lb. of silver-cadmium batteries with a power of 720 kW./hr. On either side are food stowage spaces and also light rigid crevasse bridges of 300 lb. weight. The air-conditioning system is at the rear.

Capsule "C" contains the photographic and observation dome and the photographic section, in the forward part. The centre section comprises the electronics cab containing monitoring equipment, communications equipment, television and radar equipment. The opposite side contains a mechanical and electronic repair bench and a store of standardized spares. The last section contains lunar suit stowage and air conditioning equipment.

The power trailer contains a thermionic converter for main supplies and a solar boiler with 3 kW. output for use in the event of failure of the converter for provision of essential services.

The vehicle is controlled by the driver in the conning dome who can see by closed circuit television on four channels. A boom mounted television camera is mounted above the control room with triple lens turret for telescopic work.

A direction finding aerial is mounted above capsule "B" and is used in conjunction with relays and beacons on Mt. Piton and Mt. Pico for navigation and base communication. Whip aerials (not shown) on either side provide communication with outside workers in lunar suits. The radar scanner at the rear is used both for radar survey work and for navigation using information obtained from close orbit probes.

This type of vehicle can cross crevasses up to 20 ft. in width by the following technique:—

(1) Upon approaching a crevasse the vehicle stops, and the power trailer is disconnected.

(2) Two crew lower a bridge by electric hoists to the surface, pick up the bridge and move it to the front of the vehicle.

(3) The driver lowers the crane and hook which is then attached to the bridge.

(4) The vehicle is moved forward and the bridge placed across the crevasse.

(5) The same procedure is carried out for the other bridge.

(6) Vehicle and trailer (which has its own prime mover) then cross the bridges and the procedure is reversed.

Design Criteria

The design of the vehicle was based on a number of parameters. These are:—

(1) Capsule size and weight dictated by boost vehicle capability. This dictated the use of seven capsules, each of 2 tons weight. This is within the capability of launch vehicle 4 which is about 5–7 tons soft land on the Moon, *i.e.*, the equivalent

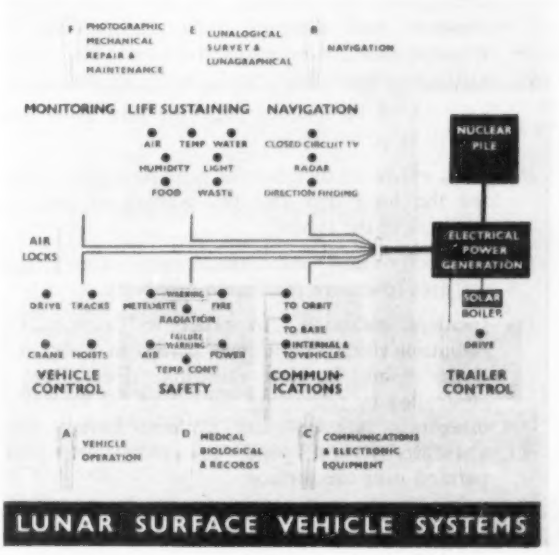


FIG. 8.

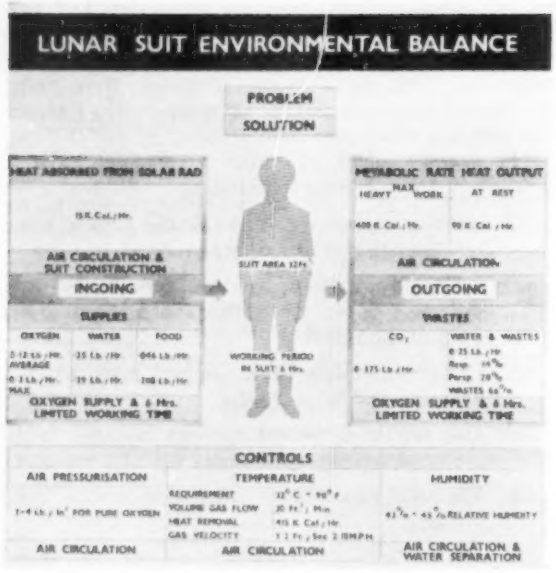


FIG. 9.

for the Saturn vehicle with nuclear staging less an extra structural weight penalty.

(2) Type of prime mover. Due to the absence of air an electrical system was chosen for the weight, duration, power and mobility required.

(3) Vehicle work programme. This dictated the number of crew, their composition and the supplies required for the time away from base.

(4) Safety requirements. Were satisfied by the use of separate capsules and distribution of the crew throughout the vehicle. A system of safety controls was designed into the vehicle. A separate power source was also provided.

(5) Nature of the surface to be traversed. This is believed to be igneous rocks or lava flows and this dictated tracks.

(6) Crew efficiency dictated the provision of a shower for the long trip and the placing of sleeping quarters in the centre.

(7) Simplicity and interchangeability are design features to ensure maximum reliability.

(8) Incident radiation. In order to decrease the radiation risk, the pile was placed in a separate trailer using forward shielding. Heat flow is controlled by restricting the use of the vehicle to temperate latitudes and a paint having poor absorptivity and good emissivity, *i.e.*, pink, painted over the surface.

A more advanced refinement may be the provision of proton deflector fields. The vehicle is double-hulled to protect against meteoroid penetration.

Crew Number and Duties

Due to the length of the lunar day and night, continuous working is required of the vehicle. It is therefore necessary to provide for two shifts of personnel to run the the vehicle on alternate watches. For this type of vehicle and the work programme laid down, the following crew composition was chosen:—

(1) Vehicle driver/crane operator—crew member "A" being fully occupied, he will not be required to perform additional duties, but could be an electronic engineer in the first shift and a mechanical engineer in the second shift.

(2) Doctor—crew member "D," can also be the botanist, biologist (life sciences), log-keeper and recorder. He will also be available for outside duty.

(3) Navigator—crew member "B," is also the vehicle and expedition leader.

(4) Photographer and monitoring engineer—crew member "F," is also the mechanical repair and maintenance engineer, on the first shift and electronics repair and maintenance on the second shift. He is also available for outside duty.

(5) Communications and electronics engineer—crew member "C"; this engineer is permanently situated in the electronics cab.

(6) Surveyor, lunalogist and lunagrapher—crew member "E"; this crew member is responsible for survey, the "geology" of the Moon, topographical mapping and direction of seismic and resistivity exploration work.

Vehicle Systems (Fig. 8)

The monitoring systems (F) monitor the air, temperature and water conditions, the pile and solar boiler outputs, air lock conditions and drive-tracks power.

The life sustaining systems involve the supply of air, water, food and light. The other necessity is the maintenance of good temperature and humidity conditions and the disposal of wastes. It is of interest to point out here that thermal control may be exercised by the evaporation of wastes and non-reclaimable water to vacuum.

The navigation system (B) is carried out with reference to information derived from closed circuit television, radar and direction finding.

Vehicle control systems (A) are basically track control for speed and direction, and selection of front or back bogies. Crane operation and bridging hoist control are other vehicle control systems.

Safety systems. Warning is given of the existence of fire, the increase in radiation intensity or damage and gas escape due to meteoroid hit.

Communications system (C). These are communications to base via repeater relays or direct communications to lunar orbit (if lunar orbits are possible) and internal communication via intercomms and to local lunar suit

wearers. This covers also television systems and radar. The trailer has a nuclear pile and solar boiler which generate electrical power for the vehicle and also power the trailer itself.

This completes the description of the lunar surface exploration vehicle.

The Lunar Suit

It is unnecessary to elaborate on the development of the lunar suit as has been adequately covered in refs. 19, 20, 21 and 22. The suit to be designed will be initially tested in vacuum chambers on Earth, then in Earth and lunar orbits and finally on the lunar surface itself. Fig. 9 show some of the problems and some of the proposed solutions.

Lunar Suit Environmental Balance

(*a*) The heat absorbed from solar radiation poses a problem. A solution is found in Billinghams construction of suit, *i.e.*, the three layer aluminium foil suit. This will be fabricated of similar material to that used on the "Echo" balloons but of thicker gauge. This was welded half-thousandth of an inch thick, Mylar with an aluminized surface. A typical cross section through such a suit would be as follows:—skin, string vest, gas ventilation space, aluminium foil insulation and pressure retaining envelope, spacer material, aluminium foil envelope, spacer and finally heavy gauge exterior aluminium foil skin. Such a suit insulates well, only allowing a heat soak from environment of 15 kcal./hr. at maximum temperature. This will be catered for by the gas cooling of the suit.

(*b*) This heat radiated from the body or metabolic rate heat output varies according to the rate at which the person is working and can reach a value of 400 kcal./hr. though at rest may be only 90 kcal./hr. This heat is carried away by the gas ventilation system and cooled in the survival equipment. A total heat removal of 415 kcal./hr. is considered maximum.

(*c*) Ingoing supplies to the body are oxygen, water and food. The oxygen requirement is catered for by a non-recoverable oxygen system and the latter by limiting the maximum duration of suit use to 6 hr. at one period.

(*d*) Outgoing wastes from the body are CO_2, water and natural wastes. This problem is overcome by the use of non-recoverable liquid oxygen system which caters for the CO_2 and respiratory water and the gas ventilation system which condenses the perspired water. Limitation of suit life to 6 hr. caters for other wastes.

(*e*) Environmental requirements of the body are a temperature of 32° C. with a 43–45% humidity. This is achieved with the ventilation system by pressurizing the suit to 3–4 lb./in.^{2} with pure oxygen and catering for a gas flow of 30 ft.^{3}/min. at a gas velocity over the skin of 3·2 ft./sec. The humidity is maintained by separating out the water content in one of the survival equipment heat exchangers, control being affected by means of a humidity sensor. The lunar survival equipment produces the volume gas flow which is then led via suitably moulded passages to adequately ventilate the whole body surface including the feet. Extra protection here is also given by the use of asbestos or rubber soles. At certain points on the suit, temperature and pressure sensors are located which feed information into the survival equipment control system to speed up or slow down the ventilation fans. Suit pressure is also maintained via a relief value on the inlet side of "oxygen to the wearer," from the survival equipment. A wrist console is worn which displays:—

FIG. 10.

(*a*) Minutes of oxygen remaining in tank.
(*b*) Suit temperature.
(*c*) Suit pressure.
(*d*) Supply amps. (battery).
(*e*) Supply volts (battery).
(*f*) Local lunar time (watch).

Lunar Survival Equipment Set

A representative survival set is shown in Fig. 10 and is of the same family of water evaporation systems described by Dr. Still.

There are four systems in such a set.

(*a*) Oxygen system. The liquid oxygen contained in the reservoir (No. 1) is replenished by the

fill/empty connection (3) and contains sufficient oxygen to last for 6 hr. This was considered the practical maximum duration for lunar suit use to overcome the waste disposal and feeding problems. The weight of oxygen in the reservoir is monitored by a mass sensor and displayed on the wrist console as minutes of oxygen remaining.

From the tank the oxygen passes via a pressure regulator (4) to the second heat exchanger (5). Here heat is extracted from the suit ventilation system and the liquid oxygen is vapourized. The gaseous oxygen then passes to a pneumatic accumulator (6) which has a pre-set "cut-in" and "cut-out" valve to ensure satisfactory lung inflation during inspiration.

Delivery pressure to the face mask is monitored by a pressure transducer (18) and should this fall below a critical pressure, the electrical supply to the heater jacket (2) is switched on by the control system (11).

As the liquid oxygen receives heat, the volume of boil-off gas increases until the pressure transducer (18) senses that correct flow conditions are restored.

A "non-return" valve and "blow off to suit" valve are fitted on the inspiration side (13) of the face mask (21). On the expiration side is a "vent to vacuum" valve (14).

It is probable that flap valves will be fitted in the face mask to cut down the "dead air zone."

(*b*) Suit ventilation system. This system is designed to deal with up to 415 kcal./hr. produced by metabolic heat and lunar suit heat soak. Gas is present in the suit on dressing and valves out to the suit pressure required on entering vacuum.

A low pressure has been chosen to allow more flexibility in the suit.

Coolant gas is pumped into and extracted from the suit via pressure (16) and suction (17) trunks which structurally support the survival set.

Air is sucked from the suit via (17) and passes through the suction fan (9) and into heat exchanger No. 1 (7). Here the humidity is reduced to the correct level and evaporated perspiration condensed into the trap (12). A temperature drop also occurs.

The cooling is achieved by controlled water evaporation (as previously mentioned) to vacuum, the cooling being proportional to the latent heat of vapourization and quantity of water evaporated.

The rate of evaporation is governed by an admittance valve (20) which allows water to pass to a vacuum vent (15). Control of this valve is exercised via the control system by a humidity sensor (19) lying between heat exchangers I and II. A further heat extraction occurs in heat exchanger II with the oxygen system as recipient.

The pressure blower (8) then recirculates the coolant gas to the suit via the pressure trunking.

As mentioned earlier the pressure and suction fan speeds are maintained via the control system by the suit thermistors.

(*c*) Control system (11). This system controls the balances in the suit to predetermined values and maintains the temperature/humidity ratios within tolerable limits.

(*d*) Electrical system is comprised of a power source of a 12 V. 300 W./hr. battery pack (10).

Other Systems

(*a*) Illumination protection system. Due to the lack of atmosphere on the Moon, the transition from darkness to light will be sudden and will probably fluctuate suddenly from darkness to values up to 30% above the maximum for Earth.

This sudden variation may cause retinal burn or damage to the eyes and could be combatted by an anti-glare visor or a system of polarizing lenses in circuit with a light sensitive element.

(*b*) Radiation protection system. In the case of radioactivity this would probably be achieved by the use of a Geiger tube with an auditory output in the helment. A dosimeter would also be attached to the suit to give a value to the total radiation absorbed.

For corpuscular radiation from the Sun from solar flares, protection would probably be achieved by the following techniques. Earth based observatories would monitor the onset of solar flares and would contact the surface vehicle via the base camp. Outside explorers in lunar suits would be notified and would seek shelter either in the vehicle or in nearby domes.

(*c*) Communication system. This would be used for line of sight only, and on the Moon would amount to 4–5 miles. Due to the action of the lunar surface as a dielectric, radio waves may propagate beyond the visible horizon.

However, this will only be of value in transmissions from vehicle to lunar suit wearer, and not in reverse due to the large antenna sizes required.

The communication system will probably be a highly directional forward facing U.H.F. transceiver with the same characteristics in gain as the human voice.

A power output in the order of a few hundred milliwatts is envisaged. An emergency signal could probably be generated by the use of an omnidirectional aerial forming part of the suit itself.

(*d*) Identification system. It would be necessary to provide for a series of identification marks as each suit would otherwise be similar. These may be painted on helmets.

This concludes the analysis of the lunar suit problem.

The Lunar Expedition

Throughout 1968–69 the final preparations will be made, the capsules being landed on the Moon in an area between Piton and Piazzi Smyth. The return vehicle will have been placed on the lunar surface and sometime in 1970 the expedition will leave the Earth in the large rockets shown as (4) in Fig. 6 to touch down near Piazzi Smyth, and Mt. Piton at the commencement of a lunar day. They will be watched by television scanners in the nearby probe rockets. Each lunar day comprises an early fortnight and so the expedition is divided into 24-hr. periods and 168-hr. periods with two of the latter in a lunar "day."

The first 24-hr. period is taken in organization and establishment on the surface at a suitable location after landing (Fig. 11).

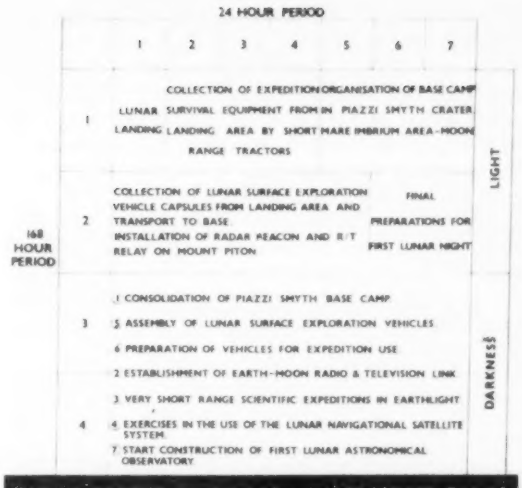
The following three 24-hr. periods are spent in the collection of the basic equipment for expedition survival from the landing area by the use of short range tractors. The next three 24-hr. periods are spent in organization of the base camp in the Piazzi Smyth crater, Mare Imbrium area-Moon. We are now at lunar mid-day. The next five 24-hr. periods will be spent in the collection and transport to base of lunar surface exploration vehicle capsules and other equipment.

Another team will visit Mt. Piton and install a radar beacon and R/T relay on the summit.

The last two 24-hr. periods before the onset of the lunar night will be spent in preparations. At last, two Earth weeks after the expedition has landed, the terminator (or day/night line) passes and the expedition lives for another fortnight in the lunar night. During this time, the Piazzi Smyth Base Camp will have been consolidated, an Earth-Moon radio and television link established, the assembly of the lunar surface exploration vehicles commenced and completed and the vehicles prepared for their journeys. If the programme is proceeding well, very short range scientific expeditions can be made in earthlight, and exercises carried out to test the efficiency of the orbital relays and navigational satellite systems.

Another task which may also be begun is the construction of the first lunar surface astronomical observatory. At last 672 hr. after the landing and 336 hr. after the Sun disappeared, the top of Mt. Piton will suddenly be illuminated and the lunar sunrise will commence. When the surface is sufficiently illuminated, the two exploration vehicles will lumber off, one to the west (vehicle A) and one to the east (vehicle B). There will be no sound due to the absence of air, and the landscape will be drab and the surface dust will fall like the wake of a ship at sea.

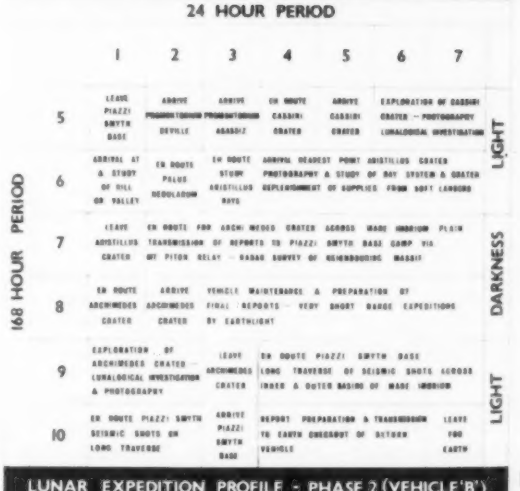
Vehicle "A" travelling at a nominal 22 miles in 12 hr. will cross two ridges in the lava flow of the Mare Imbrium *en route* to Mt. Pico (Fig. 12). During the course of the the trip seismic investigations will be made using a undirectional spread by placing delayed action shots to obtain a seismic profile.


24 HOUR PERIOD
1 2 3 4 5 6 7
168 HOUR PERIOD
1
COLLECTION OF EXPEDITION ORGANISATION OF BASE CAMP
LUNAR SURVIVAL EQUIPMENT FROM IN PIAZZI SMYTH CRATER
LANDING LANDING AREA BY SHORT MARE IMBRIUM AREA - MOON
RANGE TRACTORS
2
COLLECTION OF LUNAR SURFACE EXPLORATION VEHICLE CAPSULES FROM LANDING AREA AND TRANSPORT TO BASE
INSTALLATION OF RADAR BEACON AND R/T RELAY ON MOUNT PITON
FINAL PREPARATIONS FOR FIRST LUNAR NIGHT
LIGHT
3
1 CONSOLIDATION OF PIAZZI SMYTH BASE CAMP
5 ASSEMBLY OF LUNAR SURFACE EXPLORATION VEHICLES
6 PREPARATION OF VEHICLES FOR EXPEDITION USE
2 ESTABLISHMENT OF EARTH-MOON RADIO & TELEVISION LINK
3 VERY SHORT RANGE SCIENTIFIC EXPEDITIONS IN EARTHLIGHT
4 EXERCISES IN THE USE OF THE LUNAR NAVIGATIONAL SATELLITE SYSTEM
7 START CONSTRUCTION OF FIRST LUNAR ASTRONOMICAL OBSERVATORY
4
DARKNESS

LUNAR EXPEDITION PROFILE - PHASE 1 (BASE CAMP) Fig. 11

24 HOUR PERIOD
1 2 3 4 5 6 7
168 HOUR PERIOD
5
LEAVE PIAZZI SMYTH BASE
SEISMIC SHOOTING ACROSS MARE IMBRIUM EN ROUTE MT. PICO
ARRIVE MT. PICO
INSTALL RADAR & R/T RELAY EQUIPMENT
LEAVE MT. PICO FOR PLATO CRATER EXAMINE RUINED CRATER
LIGHT
6
IMPLEMENTATION OF PROGRAMME OF SEISMIC SHOOTING & ELECTRICAL RESISTIVITY TESTING ACROSS FLOOR OF PLATO CRATER
LUNARLOGICAL INVESTIGATION OF METHOD OF FORMATION
7
REPLENISHMENT OF OXYGEN WATER & FOOD SUPPLIES FROM STORES PREVIOUSLY SOFT LANDED IN AREA OF RUINED CRATER NEAR PLATO CRATER
VEHICLE MAINTENANCE — REPORT PREPARATION
DARKNESS
8
LEAVE PLATO CRATER
EN ROUTE FOR ALPINE VALLEY — TRANSMISSIONS OF REPORTS TO PIAZZI SMYTH BASE CAMP VIA MT. PICO RELAY — RADAR SURVEY OF LUNAR ALPS
ARRIVE ALPINE VALLEY
9
INSTALL RADAR & R/T RELAY EQUIPMENT
TRAVERSE LEFT WALL OF ALPINE VALLEY ON OUTWARD JOURNEY (70 MILES)
TRAVERSE RIGHT WALL OF ALPINE VALLEY ON RETURN JOURNEY (70 MILES)
LIGHT
10
LEAVE ALPINE VALLEY
PREPARE REPORTS EN ROUTE
ARRIVE PIAZZI SMYTH BASE
REPORT PREPARATION & TRANSMIT TO EARTH
CHECKOUT OF RETURN VEHICLE
LEAVE FOR EARTH

LUNAR EXPEDITION PROFILE - PHASE 2 (VEHICLE 'A') Fig. 12


24 HOUR PERIOD
1 2 3 4 5 6 7
168 HOUR PERIOD
5
LEAVE PIAZZI SMYTH BASE
ARRIVE
EN ROUTE CASSINI CRATER
ARRIVE CASSINI CRATER
EXPLORATION OF CASSINI CRATER — PHOTOGRAPHY LUNALOGICAL INVESTIGATION
LIGHT
6
ARRIVAL AT & STUDY OF RILL OR VALLEY
EN ROUTE PALUS NEBULARUM
EN ROUTE STUDY ARISTILLUS RAYS
ARRIVAL DEADEST POINT ARISTILLUS CRATER PHOTOGRAPHY & STUDY OF RAY SYSTEM & CRATER REPLENISHMENT OF SUPPLIES FROM SOFT LANDED
7
LEAVE ARISTILLUS CRATER
EN ROUTE FOR ARCHIMEDES CRATER ACROSS MARE IMBRIUM PLAIN TRANSMISSION OF REPORTS TO PIAZZI SMYTH BASE CAMP VIA MT. PITON RELAY — RADAR SURVEY OF NEIGHBOURING MASSIF
DARKNESS
8
EN ROUTE ARCHIMEDES CRATER
ARRIVE ARCHIMEDES CRATER
VEHICLE MAINTENANCE & PREPARATION OF FINAL REPORTS — VERY SHORT RANGE EXPEDITIONS BY EARTHLIGHT
9
EXPLORATION OF ARCHIMEDES CRATER — LUNALOGICAL INVESTIGATION & PHOTOGRAPHY
LEAVE ARCHIMEDES CRATER
EN ROUTE PIAZZI SMYTH BASE LONG TRAVERSE OF SEISMIC SHOTS ACROSS INNER & OUTER BASINS OF MARE IMBRIUM
LIGHT
10
EN ROUTE PIAZZI SMYTH SEISMIC SHOTS ON LONG TRAVERSE
ARRIVE PIAZZI SMYTH BASE
REPORT PREPARATION & TRANSMISSION TO EARTH CHECKOUT OF RETURN VEHICLE
LEAVE FOR EARTH

LUNAR EXPEDITION PROFILE - PHASE 2 (VEHICLE 'B') Fig. 13

Finally we arrive at Mt. Pico and place a radar beacon and R/T relay on the summit. This mission completed, the vehicle then takes a northerly course over the outer Imbrium basin investigating a flooded and ruined crater south of Plato. Thirty-five miles from Pico we arrive at a point on the ring wall of Plato which has collapsed, we are also near a valley entrance leading to the interior of the crater.

For the last 336-hr. period of light we can, with alternate teams, carry out a programme of seismic investigation of the crater floor using calibrated rockets for "air" shooting having shaped charge heads, probably using a split spread; fan shooting may also be carried out for local investigations.

Another team will probably carry out a geophysical electrical resistivity test to compare the results with a resistivity exploration made on the meteor crater in Arizona by Jakosky, Wilson and Daly in 1932 (ref. 23). These tests will be done using low frequency alternating current apparatus. One of the current electrodes will be maintained at the same position whilst the outer electrode and the two intermediate probe electrodes will be progressively moved out to give a depth section. Night will then fall.

The first half of the dark period will be spent in replenishment of the oxygen, water and food supplies from stores previously soft-landed in the area of the ruined crater and also essential vehicle maintenance. Reports will also be prepared and transmitted when the vehicle has left Plato at the start of the second 336-hr. period of darkness. The pico station will relay the information automatically. During the course of the traverse to the alpine valley a radar survey will be carried out of the lunar alps and the vehicle will cross a pressure ridge.

The vehicle arrives at the entrance to the alpine valley coincident with the start of the lunar day. Radar and R/T relays are installed on the summit of Mt. Blanc and a traverse of the lunar valley is completed. Thirty-eight days after leaving base the vehicle arrives back at Piazzi Smyth.

Meanwhile the second vehicle (Fig. 13) which left the base at the same time and went to the east (vehicle B) has done a similar trip.

Leaving Piazzi Smyth the vehicle has crossed to the lunar alps at Pr. Deville. Surveying by radar, it has passed by Pr. Agassiz to end at Cassini Crater on the Palus Nebularum. Cassini is then investigated with the same techniques as Plato and the vehicle proceeds to a large fault, cleft or rill which is explored. The next point of call is the Aristrillus crater where photographs are taken and the ray system examined. The vehicle is then replenished from soft-land vehicles, and reports for base are prepared.

At the commencement of the first period of lunar darkness, the vehicle leaves Aristillus in earthlight and the reports are transmitted to base via Mt. Piton relay. A radar survey of the neighbouring massif is conducted. Finally after crossing a pressure ridge the vehicle arrives at Archimedes. Final reports are prepared and local expeditions are carried out together with vehicle servicing and maintenance.

When daylight comes the Archimedes crater is scientifically examined as was Plato by photography and mapping. The last work done by this vehicle is a long traverse of the outer and inner basin of the Mare Imbrium, with a undirectional spread and a seismic profile obtained, the two vehicles should arrive back at base together. The next 3 days are spent in data transmission and return vehicle preparation and loading.

Finally on the last day of the lunar light period at the end of a 10-week sojourn on the Moon, the return vehicles will take off on their homeward journey.

After 4 days they will enter the upper limits of the Earth's atmosphere having completed the first expedition to another planet in space.

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The opinions expressed in this paper are the personal views of the author and do not necessarily represent the views of Hawker-Siddeley Aviation, Ltd. Particular thanks are due to Mr. Ernest Claydon, Mrs. José Davies and Mr. John W. Wood for the illustrations, without which this paper could not have been adequately presented.

Moonwatch in the United Kingdom

By L. J. CARTER, A.C.I.S.

The first attempts by the Society to organize optical observations of satellites were made in November, 1957. Observation notes were hastily prepared and a draft report form devised which remained in operation for over a year. At that time an attempt was also made to undertake radio observations but this idea was not proceeded with owing to lack of support.

Publications issued by the Society reflected this interest, *e.g.*, the *Journal* for May–June, 1958 contained an article on "Project Vanguard: Mark II Minitrack System" while *Spaceflight* for July, 1958, included Mr. M. J. Hendrie's article on "The Photographic Observation of Artificial Satellites." Preprints of both articles were distributed widely in order to encourage further interest.

On 10 June, 1958, the Smithsonian Astrophysical Observatory promised to loan the Society twenty-four M-17 elbow telescopes employing 120 mm. objective lens with wide-angle Erfle eye-pieces. The overall field of view of each telescope is just over 6° with power 8x. The original consignment was followed by another ten later.

At present the B.I.S. operates three active Moonwatch teams with a fourth in course of organisation. Some of the teams have cameras for making photographic observations, while all have adequate time-keeping facilities. Several have available in addition a number of telescopes of much higher magnification.

Each team is under the control of a team leader who may appoint one or more deputies. Details of the teams at present in operation or projected are as follows:

Name of Team	*Team Leader*	*Address*
1. *Scottish.*	Dr. A. E. Roy.	Astronomy Dept., The University, Glasgow, W.2.
2. *High Down. (Isle of Wight).*	S. T. Smith.	Pippins Cottage, Church Hill, Totland Bay, Isle of Wight.
3. *Bristol.*	J. Carter.	7, Hurlingham Rd., Bristol.
4. *Midlands.*	J. D. Llewellyn.	80, West Green Drive, Stratford-on-Avon, Warwicks.

There is no requirement that members of the team have to be members of the Society and, in fact, a number of them are members of local astronomical bodies or others who are mainly interested in astronomy but who would like to help in this way.

In addition to the teams, about forty observers also belong to the organization though they operate as independent observers and have proved themselves particularly adept and resourceful in observing large bright satellites.

Some of the observers use "Norton's Star Atlas," while others use the "Skalnate Pleso Atlas" by Becvar. If "Norton's Star Atlas" is used with a stop watch (having a minimum error of ± 2 sec.) the atlas is not accurate enough because positions have to be given to ± 0 : 1 in declination and a corresponding accuracy in R.A. of about ± 0·5 for zero declination.

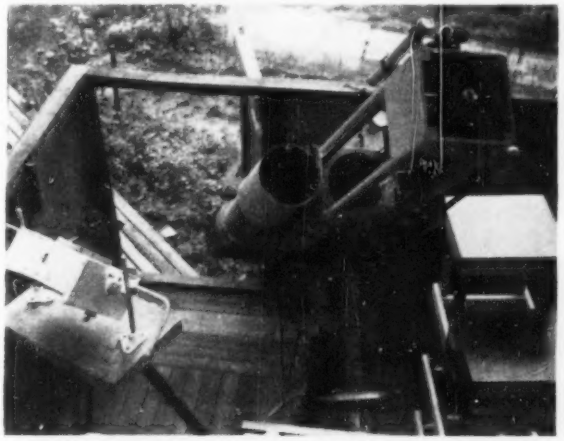
Where neither atlas nor an equivalent is available, observations are forwarded based on comparative stars, *e.g.*, 3/10 α to δ Cam., $1\frac{n}{7}$ 110 to 111 Her., etc.

Satellite Prediction Sheet issued by D.S.I.R. to each team consist of the following:—

(*a*) Instructions on the use of predictions.

(*b*) Map of Western Europe.

(*c*) Transparent tracking diagram.



Mr. M. J. Hendrie's observatory at Wormingford, Essex. Equipment includes a clock-driven equatorially-mounted 6-in. reflector with 1- and 2-in. finders. Telescope carries two cameras, usually a 14-in. focal-length f/5·6 and a portrait lens camera of about 9-in. focal-length. There are also 2 and 3-in. portable refractors (and a 5-in. refractor not at present in use). The satellite tracking camera is visible in the picture and was built by the University of London Observatory from whom it is on loan. There is an observatory pendulum sidereal clock and another clock for GMT. A home-made chronograph is available and this is connected to a tapping key near the telephone so that the Speaking Clock may be recorded directly on to the chronograph record alongside the observation charts. Catalogues, darkroom equipment, a calculation machine and a blink microscope are available, principally for comet work.

M. J. Hendrie

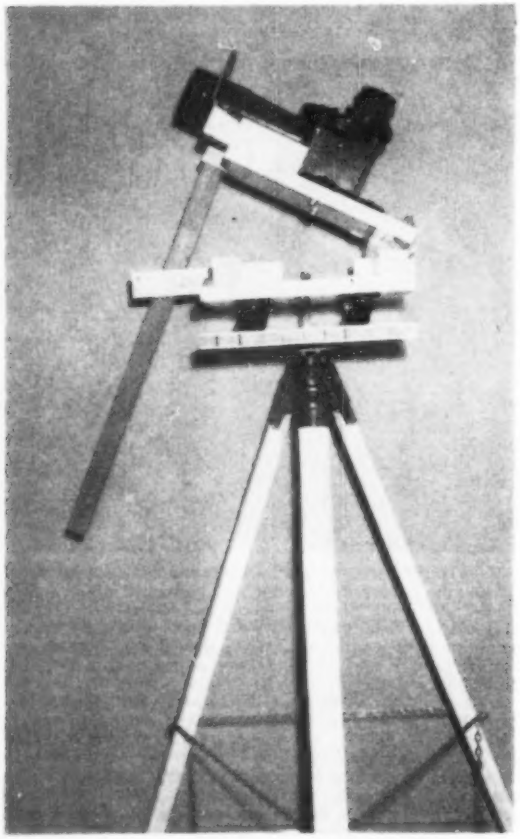
(*d*) Prediction sheet, giving the setting up of the diagram relative to the map.

(*e*) Table of heights at each minute mark on the track.

Item (*d*) is normally issued weekly and items (*c*) and (*e*) at fortnightly intervals.

Visibility conditions are included in the notes at the end of each prediction sheet. This information is given in terms of the longitude with respect to the Apex at which the satellite enters or leaves the Earth's shadow for certain days during the prediction period. This enables observers to plot the position on the track diagram at which the Earth's shadow intersects the orbit. Also included in the notes are the times of nautical twilight (Sun 12° below the horizon) on the Greenwich meridian for different latitudes, to provide observers with an estimate of the darkness of the sky at the time of the observation.

This material is not normally made available at once to independent observers, though each of them receives a copy of the Royal Society Instruction Notes on making optical observations, together with regular predictions issued by D.S.I.R. (which nowadays come out once or twice weekly), together with the weekly *Satellite News Bulletin*.



Moonwatch telescope built by the B.I.S. Midlands team.

The last mentioned is a duplicated newsheet issued entirely for the benefit of independent optical observers but contains not only information about the teams and observations generally, but also includes notes of wider interest, *e.g.*, projected satellite launchings, plans for future developments, etc. Some of the subjects dealt with in recent issues are as follows:

(*a*) Solar power unit.

(*b*) Communications satellites.

(*c*) Satellites inflated with plastic foam.

(*d*) Needles as relay satellites.

(*e*) Nuclear rockets—cost proposals.

(*f*) "Active *v.* passive satellites."

(*g*) Weather satellites.

(*h*) Technical advances through space research.

All observers receive this material in return for an annual subscription of 15s., this covering the receipt of material from 1 July to 30th June the following year. The price is based entirely upon the cost of postage involved in sending out predictions, etc., most of which are distributed twice weekly during a period of satellite activity.

Observation report forms are distributed free of charge regularly and can be obtained by any observer either in the Moonwatch organization or not upon request. In addition, separate observation forms are also available where photographic observations are being made. Both forms contain full details of the procedure to be followed.

In addition to general observations made by both the teams and independent observers, special projects are sometimes allocated to the teams, *e.g.*, in connection with a projected launching of particular importance. One such example concerned the launching of the Echo satellite in August, 1960, which provided the Scottish Moonwatch team with their greatest spell of activity so far. A large proportion of clear weather during that period enabled the team to participate in the worldwide search and over forty observations by the team were sent to the Smithsonian Astrophysical Observatory and to the D.S.I.R. Radio Research Station, Slough.

These observations were made with the naked eye, with the team's M-17 Moonwatch telescopes, and with the University of Glasgow's Department of Astronomy's 8-in. refractor.

The naked-eye observations were mostly coincidences of the balloon with brighter stars, the time of the coincidence and the co-ordinates of the star being noted. On a number of occasions the satellite was timed when it passed between Altair and a neighbouring star.

On the first few passes of the satellite, the Moonwatch telescopes were set up in fences in the usual manner since it was not known if the balloon would achieve complete inflation and therefore naked-eye brightness, but when it became clear that it was as bright as Altair and would remain so for some length of time, a new

technique was adopted. Immediately it became visible, each member of the team sought to get it in his telescope and obtained a reading at his leisure, his telescope setting being ascertained after the satellite had passed. This "fire when ready" technique enabled most of the team to participate directly and gave them a great deal of practice. Afterwards, the results for a particular pass were each reduced and graphed azimuth against time and altitude against time. Errors in reading scales, etc., were immediately disclosed by these points lying far off the graph and before sending in the results, these readings were rejected.

The relatively slow angular motion of this satellite also enabled it to be held fairly easily in the 8-in. refracting telescope and by noting the star background, positions and times were easily obtained.

Both the independent observers and the teams are in touch with H.Q. by means of an intricate communications system, which enables important observations to be transmitted to America within a matter of minutes, and so fed into the computer which is then engaged in obtaining more accurate predictions for subsequent passes of the satellite.

Each team leader is aware of the procedure for communicating these observations without delay. Where H.Q. is alerted (which occasionally means that the staff have to be available all night!), the observations can be phoned through and are then re-transmitted via a special cable system from a separate telephone which enables the observation to be received in and transmitted out at the same time.

The author has been appointed liaison officer for Moonwatch facilities in this country and is responsible for all organization and control. As he is also a member of the Royal Society Committee concerned with optical tracking of satellites, this ensures that observers

THE BRITISH INTERPLANETARY SOCIETY

REPORT FORM

VISUAL OBSERVATION OF AN ARTIFICIAL SATELLITE

Satellite designation *Date* *d.* *m* 196 G.M.T.

Observer's name

Address/Team

Observer's co-ordinates† *Lat.* N

Long.

*Observing conditions** Best possible/very good/good/fair/poor/very poor
*Quality of observation** Best possible/very good/good/ fair/poor/very poor

Brightness Mag *Flashing** YES/NO *Period* sec

*Observed positions** *R.A.* *h.* *m.* *s.* *Dec.*

(A) if map used. 1.
2.
3.

(B) by Star fixes, i.e., position relative to two identified stars in terms of the line joining them and the point of crossing interpolated or extrapolated.

Star Fixes		*Time of Passage (G.M.T.)*		
A: B:	*AS* = — AB 10	h	m	s
C: D:	*CS* = — CD 10	h	m	s
E: F:	*ES* = — EF 10	h	m	s

Colour or other observing notes

* Delete as applicable.
† Coordinates taken from the Ordnance Survey 1 in. grid map are sufficient for the prediction service, who can easily convert to lat. and long.

Mr. L. J. Carter (right) with members of the Bristol Moonwatch group.

are kept fully informed of potential activities of interest to them.

Last August, the author was also elected to the International Tracking Committee of the International Astronautical Federation at the Congress in Stockholm. On that occasion it was decided that the Committee should be re-constituted with Professor Tabanera (Argentine) as Chairman and Werner Buedeler (Germany) as Secretary. The terms of reference of the new Committee are not very clear and the immediate steps it can take are still under discussion. However, there are several useful things it could undertake in order to provide information from each country, and to encourage the experience of Moonwatch teams either arising from an exchange of visits or published material.*

The problem of keeping observers in touch with satellite launchings is quite substantial. From time to time lists of successful satellites are circulated but this has now grown from a single sheet to a small booklet, and the accelerated range of launchings projected by N.A.S.A. over the next few years would indicate that this will become quite a sizeable volume.

Members of the B.I.S. and others who are interested in joining teams or in taking part in optical observation of satellites generally are invited to register as active observers. Those living near a team should write to the team leader, but others should apply to H.Q. for a registration form which calls for details of the observer, his co-ordinates, and instruments available.

A large number of questions from observers are dealt with in the pages of the S.N.B. These not only involve requests for practical help but also general inquiries about satellite launchings, rocket vehicles, and astronautics generally. The S.N.B. is quite an informal publication and has been edited by the author from its inception. To date over 100 different issues have been distributed. Active observers occasionally receive copies of the *Bulletin for Visual Observers of Satellites*, issued by the Smithsonian Astrophysical Observatory. This is quite a useful publication but insufficient copies are received to go round. However, a few copies are always retained for loan purposes. In addition, a fair number of reports and other literature of particular interest to observers is listed in the S.N.B. as being available for loan.

** It is not clear how many Moonwatch teams are controlled by the I.A.F. but a rough guess would put it at over forty.*

A FEW NOTES ON THE VARIOUS TEAMS

Glasgow

There are thirty-two people in the team, including lecturers in astronomy, navigation and mathematics, a surveyor, and several other persons with training in astronomy and mathematics.

The team is situated at the University Observatory. It has 12 Moonwatch telescopes, a camera, excellent time-keeping facilities and access to other instruments as required.

Bristol

This consists mainly of members of the Astronomical and Astronautical Society affiliated to the University of Bristol Union. The team consists mainly of student-members, though some of these have had previous experience as amateur astronomers. The observation site on a tower of the University Physics Building known as the Royal Fort, has a perfect view of the whole sky, and in this respect its high position is an advantage, though it does mean that the site is exposed to winds—particularly cold ones!

In addition to ten M-17 telescopes, the team has the use of a chronograph loaned by Mr. A. F. Collins for recording the times of observation. Mountings designed for use on either equatorial or altazimuth stands are made in the University engineering workshops and charts which were devised and drawn by the group enables the declination and right ascension of the satellites predicted positions to be determined in a matter of minutes. The use of this method makes it practicable to group the telescopes along the predicted path of the satellite, as opposed to the standard Moonwatch method of setting the telescopes with overlapping fields of view which lie across the path.

High Down (Isle of Wight)

The High Down Moonwatch Team is confined to employees of Saunders Roe, Ltd., most of whom are employed on the Black Knight rocket project. The team is formed in the nature of a club with a building within the outer boundary fence of High Down Rocket Test Site. It stands by the approach to Old Needles Battery overlooking the Needles lighthouse, with Alum Bay cliffs about 30 yd. to the North and Seratell Bay cliffs about 20 yd. to the South. The team numbers about thirty-three persons so far and has available five M-17 elbow telescopes, two stop-watches, private radios, etc. The team had its greatest success on 17 May last year when four observations were made within an hour, two each on 1960 Gamma I and 1960 Gamma II.

Midlands

This new team is in course of formation and has four Moonwatch telescopes, plus camera and stop-watches.

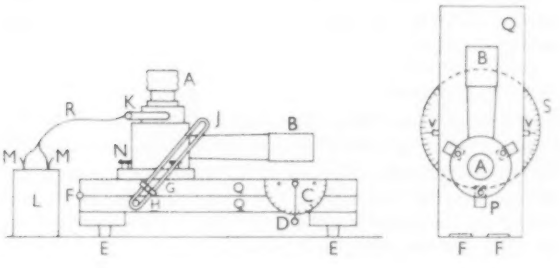
The Glasgow Moonwatch System

By A. E. ROY, B.Sc., Ph.D., F.R.A.S.

The Glasgow Moonwatch Station was set up in 1959 to observe visually those artificial satellites that had orbital inclinations large enough to bring them into high northern latitudes. The Station is based on Glasgow University Observatory (latitude 55° 52′ 26·25″ N, longitude 17m 09·70s W, height 45 metres) and the team members are drawn mostly from the Scottish Branch of the British Interplanetary Society and from the Astronomical Society of Glasgow. The team is directed by the present author, assisted by Mr. J. S. Griffith, B.Sc., F.R.A.S., also of the staff of Glasgow University Department of Astronomy.

Instruments used have been sent on loan from the Smithsonian Astrophysical Observatory, Cambridge, Mass., U.S.A., or constructed specially for this work, or were already installed in Glasgow University Observatory. The system of observing adopted at Glasgow was designed to obtain timed positions of satellites as accurate as non-automatic observations could give.

The main disadvantage found lies in the poor seeing conditions experienced in and around the city of Glasgow for part of the year, but this defect is outweighed by the many advantages obtained in using the facilities of the Observatory.



Dr. A. E. Roy.

Observing Equipment

Twelve M-17 elbow-type telescopes, of objective 60 mm. diameter, are used. Each telescope has a field of just over 6° so that an artificial satellite usually remains at least 6 sec. within the field if crossed centrally. Indeed ECHO, the American balloon satellite, can remain over 30 sec. within view.

The first mountings used for the telescopes were simple and robust alt-azimuth stands, details of which are shown below. Concrete platforms, with 2-ft. square tops, already in existence in the Observatory grounds, were used as stands for the mountings of some of the telescopes, tables being used for the others.

Satellite telescope—Key to principal components.

A *Rubber eye-piece,*
B *Objective end of telescope,*
C *Protractor with half-degree scale,*
D *Freely swinging plumb-line,*
E *Rubber studs,*
F *Hinges,*
G *Butterfly screw*
H *Swivel pin*
J *Brass, slotted plate*
} One on each side of mounting.
K *Lamp-holder,*
L *Six-volt battery,*
M *Crocodile clips,*
N *Screws,*
P *Countersunk metal plates in upper plank to take screws,*
Q *Plank,*
R *Twin flex,*
S *Large circular protractor,*
V *Indicator.*

The back of the celluloid protractor on each telescope is painted white and the position may be read to 15′. From the reading is obtained the angle of the protractor's straight edge to the horizon. In general this angle is not the same as the angle between the line joining the intersection of the telescope cross-wires to the centre of the telescope object glass and the horizon since it is unlikely that this line is strictly parallel to the straight edge of the protractor. This instrument error is measured and checked periodically so that in setting a telescope at a desired altitude the error can be allowed for. A simple way of measuring the errors is described later.

The bulb in the lamp holder is red-shaded and is necessary to illuminate the cross-wires which are in fact etched. The crocodile clips form a convenient method of making and breaking the circuit.

The brass plates J swivel at H as the telescope is raised in latitude.

The graticule supplied with the M-17 telescope has a vertical and a horizontal line etched in it, dividing the field into quarters. The graticule was removed and the vertical line was marked off in degrees and half-degrees by small horizontal lines (the half-degrees being indicated by smaller lines than the degree lines). The passage of a satellite across the vertical line can with a little practice be estimated to better than plus or minus 4′. The much slower passage of a star enables its position on the vertical line to be measured to within plus or minus 2′.

Observing at the 8-in. refractor which has been used to track the American balloon-satellite, Echo I.

Many Moonwatch teams set up a post to mark the meridian and use the post itself as the centre of the telescope field, noting the times when the satellite disappears behind the post and re-appears.

The method first adopted at Glasgow used the Pole Star (Polaris). The altitude of Polaris is roughly the latitude of the observer (which is known). The telescope was set at this altitude so that Polaris appeared in the field when the telescope was pointed approximately to north. The telescope was then adjusted so that the star was hidden by the intersection of the cross-wires and finally clamped, the time being noted on the sidereal clock. This time, with a knowledge of the latitude, and using the Pole Star Table of the "Astronomical Ephemeris" (formerly the "Nautical Almanac")[1], gave the altitude and azimuth of Polaris.

The altitude, compared with the protractor reading, gave the protractor error. The telescope, taking this error into account, could then be set at any desired altitude for satellite-spotting.

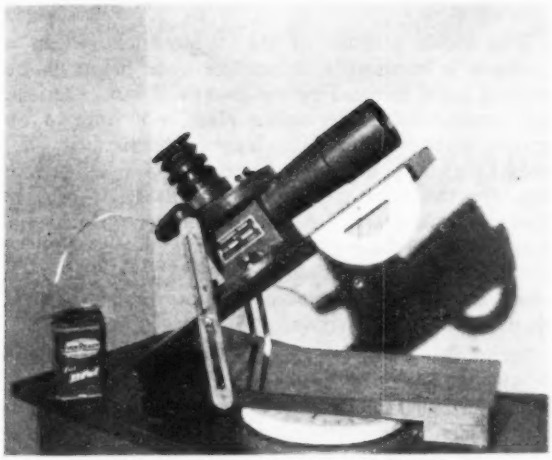
The azimuth of Polaris was the azimuth east or west of the meridian of the telescope at that time. This angle was substracted from the desired azimuth to obtain the angle through which the telescope was to be rotated. A large 10-in. diameter 360° protractor (a diameter smaller than the distance between the front and back pairs of rubber studs) was slipped under the telescope stand as shown in diagram I so that the indicators lay on a line joining points 180° apart. The indicators are made of small metal strips strapped under the lower plank of the telescope stand, roughly at 90° to the telescope collimation axis. The protruding ends of the indicators were turned vertical so that the observer could avoid a parallactic error by reading only when his eye was immediately above the indicator end. The telescope mounting was then rotated through the desired angle.

The above system can be used to set up the telescopes in altitude and azimuth to within half a degree in angle.

On a small number of occasions, however, the Pole Star has been obscured when other areas of the sky have remained clear, thus preventing the above method being used. This frustrating situation is no longer experienced since we can now use the projecting roof-edge of a nearby building as a reference point in altitude and azimuth, its altitude and azimuth for each telescope-stand's position having been found using the Pole Star method outlined above.

Timing Apparatus

Glasgow University Observatory possesses a Riefler sidereal clock in a partially-evacuated glass case and this clock sends second impulses to a chronograph. The circuit for the manual tapper on the chronograph was modified so that each of the twelve observers at the Moonwatch telescopes could record the time of passage



A Moonwatch M-17 telescope and its alt-azimuth mounting.

of a satellite or star through his telescope field by the chronograph via a tapping key. The position of such a mark on the tape can be read to one-tenth of a second of time. A rate and error book is kept for this clock.

Since all twelve tapping keys were connected to the same channel on the chronograph tape it was essential to find a foolproof method of assigning marks on the tape to the correct tapping key. In the first method experimented with, any observer pressing his key shouted "now" together with the number of his telescope. This enabled a team member in charge of a chronometer to record the time of the event. This method, however, did not take into account the person who accidentally pressed his tapping key, something all too easy to do. Because of this, some experimentation was made with an indicator box. In this method, each tapping key circuit was led through the box which contained a numbered bulb and relay for each key. When a key was pressed, the appropriate bulb lit up and remained lit until the switch under it was pulled. The team member in charge of the box recorded the telescope number and the time from the chronometer lying beside the box. This method is more satisfactory but it is hoped, however, that by the time this appears in print, a 13-channel chronograph will have been completed, thus eliminating finally all conceivable sources of error.

The Method of Observing

From the predictions received by Glasgow Moonwatch Team from the Department of Scientific and Industrial Research Radio Research Station at Slough and the Moonwatch Headquarters at the Smithsonian Astrophysical Observatory, Cambridge, Massachusetts, U.S.A., azimuths and altitudes are chosen for each telescope. The telescope settings are dictated not only by the necessity of forming one or more optical fences of interlocking fields across the predicted satellite paths but also by the irregular skyline surrounding the Observatory. For example, for a satellite whose orbit is relatively accurately known, four fences of three telescopes each may be chosen, each fence being of length 16°, an overlap of 1° in telescope field. In contrast to this, a satellite whose orbit is only roughly known may be sought with one fence of twelve telescopes, of length 61°. The latitudes are found for the middle of each fence from the predicted satellite heights and ranges with the aid of G. E. Taylor's graphs.[2]

The telescopes can then be set up by the method of section 2, each observer being given a duplicated copy of the telescope graticule to a scale of 1 in. equal to 1°. When the satellite reaches the vertical line in his field, the observer presses his tapping key. He notes the point at which the object crosses the vertical line and its path across the field. On the copy of the graticule which he illuminates with a red-shaded torch he draws the path as accurately as possible paying special attention to the point at which it crossed the vertical line. His next procedure is to put in carefully the positions of the stars visible in his field, paying attention to their different brightnesses. With a little practice he can complete this task in about 1 min. By the end of this time the last stars he marks in will have moved a maximum of 15′ from the positions they occupied when the satellite passed through his telescope field. The distortion of the star field due to this cause is therefore small and indeed allowance for this distortion may be made if the convention is adopted of (i) marking in the stars from the edge of the field to which they are moving, (ii) drawing in an arrow to indicate their direction of movement. Finally the observer makes sure he has noted the azimuth and altitude of his telescope.

The Reduction of the Observations

Two methods of arriving at the satellite position for which the time was noted are described below.

Method I. In this method the stellar background is neglected—on occasion it may not exist—and the satellite's position is given in altitude and azimuth, its azimuth being the azimuth of the telescope. To the altitude of the telescope is added or subtracted the angular interval between the centre of the graticule and the point at which the satellite crossed the vertical wire. This procedure gives an altitude and azimuth for the satellite probably correct to plus or minus half a degree. Confirmation of this accuracy was obtained by observing 1960 IOTA 1 (the American balloon satellite ECHO). Sets of observations in altitude and azimuth, obtained for a number of appearances of the satellite were graphed and it was found that for each set the majority of the points lay within half a degree of the smooth curve drawn to fit them.

Method II. This method utilizes the stellar background marked on the copy of the graticule.

The noted altitude and azimuth of the telescope, together with the local sidereal time of the observation, are used to obtain the rough right ascension and declination of the telescope field. To do this easily the set of

Reading timing marks on the chronograph tape.

two concentric stereographic nets designed by Kohlschütter[3] for the solution of spherical triangles is used. The accuracy of this useful device is one-half degree, of the same order as the accuracy with which the telescopes may be set up. Firstly the altitude and azimuth may be converted into hour angle and declination by Kohlschütter's device. The relation[4]

local sidereal time = hour angle + right ascension

then gives the right ascension of the centre of the telescope field.

This, together with the declination, enables the observer to choose from the "Skalnate Pleso Star Atlas"[5] the region of the sky that must contain the stars he observed. Having identified them from his chart, he can then read off from the "Star Atlas" the right ascension and declination that the satellite had at the local sidereal time he pressed the tapping key. The greater accuracy of this method makes it preferable to the first method.

The final step in both methods is to convert the local sidereal time to Greenwich Mean Time by using the "Astronomical Ephemeris"[6] in the usual way.

Conclusion

The above account of the Moonwatch system at Glasgow is necessarily incomplete since before it sees print changes dictated by the growth of our experience will undoubtedly have taken place, not only in our apparatus but also in our observing techniques. It is hoped that more accurate and less inconvenient mountings for the telescopes will be available, also a 13-channel chronograph. Again, to achieve our stated goal, namely the production of timed positions of satellites as accurate as non-automatic observations can give, observations will be reduced by more refined methods than those outlined above.

Incomplete though this account is, however, it may not be without value or interest to other observers in this new field of artificial satellite tracking which has presented the astronomer with observational problems never before encountered. In passing, it may be said that organizational problems too can arise in running a Moonwatch team that are unprecedented in more regular astronomical circles. For example, since weather is notoriously unpredictable in its behaviour in Britain, and since the number of clear nights in the year is not large, notification of team members by post of coming Moonwatch meetings merely results in a discouragingly large proportion of cancelled meetings or in the non-utilization of some clear nights. The present system in use in Glasgow is that team members, on their own initiative, phone the University Janitors' Box on any clear night after 6 p.m. to find out if a meeting is called for that night and if so, at what time. In addition, of course, circulars may be sent out to members or 'phone calls made if a special operation is scheduled such as the launching of a new satellite. This system works surprisingly well, enabling last-minute decisions to be taken.

In conclusion, I would like to record my gratitude to the former Director of Glasgow University Observatory, Professor W. M. Smart, and to the present Director, Professor P. A. Sweet, for their interest and encouragement, also to my colleagues Dr. M. W. Ovenden and Mr. J. S. Griffith for their help and guidance, and to the members of the team who have turned out time and time again to their post-sunset and pre-dawn vigils and without whose efforts the station could not continue to function.

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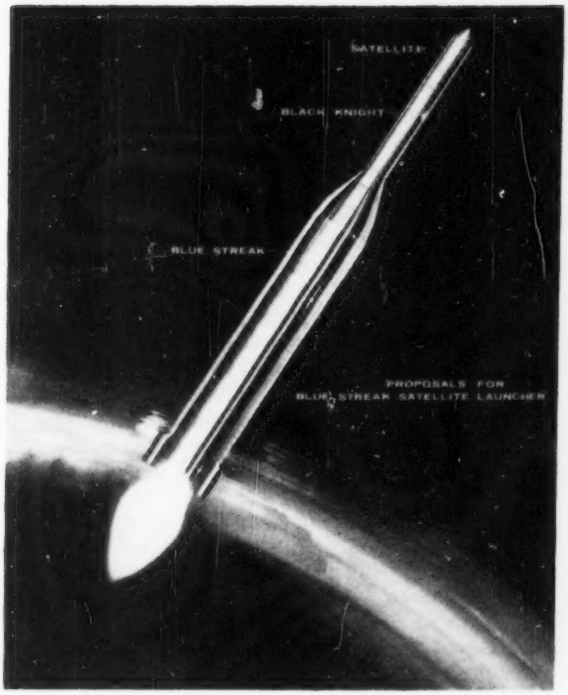
British Participation in Space Research*

By E. G. D. ANDREWS,† A.M.I.Mech.E.



Introduction

It has been suggested that Britain should take advantage of its exceptional opportunity and adapt the De Havilland "Blue Streak" and the R.A.E./Saunders Roe "Black Knight" to create a basic launching vehicle for satellites. That Britain ultimately will undertake the launching of satellites to me is hardly in doubt, but what makes the present decision critical for the next few years is the inevitable redeployment of the technical team that has been working on "Blue Streak." Without the development of a major ballistic missile in this country, there would be a lack of facilities for training the large number of specialists required for a space programme, and the formation of a technical team in an advanced discipline is a long and expensive operation. It is this, rather than the deterioration of existing facilities and the increasing obsolescence of existing designs, that would necessitate another large investment if a similar activity were recommenced in a few years' time.

Perhaps because of the far reaching effect of the Government's decision on our advanced technology, all the arguments put forward have concentrated on the immediate potentialities of this particular combination of vehicles, and on the opportunity that exists of launching satellites at little extra expense. Britain could undoubtedly afford to finance this particular exercise, and its international prestige as an advanced manufacturing nation would undoubtedly benefit, but it might well be asked whether this is not too short a view to take. As a responsible Society we must not propose to squander the nation's resources but must ensure that it gets the best return from its investment, and this requires that we look considerably further ahead than the next 5 to 10 years. At the end of that time we must still be in a very good position to proceed with the next, more ambitious, project without the necessity for wholesale re-equipment.

* *A lecture given at a meeting of the British Interplanetary Society in London on 19 November, 1960.*

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Necessity for a Space Programme

Even before discussing this, however, we must be sure that we ought to advocate a space programme at all. Great Britain is not so wealthy that it cannot find useful outlets for its surplus resources, and it has a creditable social conscience that compels it to accept some responsibility for the welfare of communities to whom the provision of adequate food and shelter is problem enough. We must not let our enthusiasms or vested interests blind us to the fact that a space programme cannot be justified unless it makes some contribution to the continued prosperity of the nation.

That Britain should engage in space research is generally agreed, and it is in fact doing so already. The compulsion is that it cannot exist except as an exporter of quality products and must therefore keep abreast of scientific developments. Unless our physicists and astronomers have facilities to permit them to carry out their own experiments in space, they will be debarred from making discoveries in, and original contributions to, many important fields of enquiry.

The same is true of technological developments. The extremely stringent requirements regarding the weight and performance of the equipment and propulsion of the top stage impose an incentive for developments which would probably never be attempted if the incentive did not exist. If previous experience can be taken

as a guide, these are likely to have repercussions on commodities which can be sold in the international markets. It is perhaps not realized as widely as it ought to be that advanced technological development is every bit as valid an investment for the future as pure research.

Since these advantages appear to be associated with the top stage, the doubt has been raised whether Britain need concern itself with the costly development of the lower stages. There are, however, four other considerations to be taken into account. Britain has already spent a large part of the cost of developing Blue Streak and Black Knight and, in collaboration with Australia, already built suitable launcher pads and engine test beds. The additional cost to complete the development and provide vehicles might well be lower than the cost of American equivalents, as undoubtedly the price of the American vehicles would include a large sum to help amortize their total development costs. The relevance of this argument however depends on the quantities involved.

Secondly, although comparatively inaccurate orbits are interesting at present, this will not always be the case. The significant difference between the Blue Streak satellite launcher and many American launchers is that it is proposed to propel the top stage right up to the point where it enters its orbit, and is under control the whole time, as opposed to an unguided top stage.

The third consideration is the degree of control which could be exercised over the design of American launching vehicles. Since the success of the experiments is vitally concerned with the behaviour of the lower stages Britain cannot be unconcerned about this.

Lastly, if there are important commercial applications of space vehicles we may find that Britain is at a serious disadvantage. There have been indications enough in the last few years that American commercial competition is not solely a matter of quality and cost, and there may be very strong opposition to a proposal that Britain should use American facilities and vehicles to launch equipment in competition with American equivalents. If it were found that, after all, there were military uses for satellites, the same difficulties might arise.

Typical of possible commercial uses is the communication satellite. This is likely to be of more value to the British Commonwealth than to any other single community in the world. Australian and New Zealand newspaper editors, for instance, have told me that this is one development for which they are longing because the breakdown of existing radio communications has starved their countries of news, sometimes for days. If it is found, as seems likely, that the best technique is to amplify the signals as they arrive at the satellites and before they are transmitted back to ground, the number of signals that can be handled by one satellite will be limited. In any case the ground equipment will have to be matched to the capabilties of the satellite. British satellites will probably be essential if British radio manufacturers are to sell equipment even to the British Commonwealth.

Other commercial uses for satellites have been proposed, but the list will not be complete for many years. Since these will be tangible benefits, it might be wise in the early stages to concentrate on them even to the exclusion of all else, because they will win support for the vehicle. Commercial exploitation of satellites will be greatly assisted if the payloads are large.

Policy Considerations

Satellites and launching vehicles are a means to an end and have no intrinsic value. There is no merit in achieving a prodigy of miniaturization in a satellite, and providing for it an optimum launching vehicle, if the same measurements or commercial advantages can be obtained at less expense by using conventional aircraft techniques and a launcher that is larger than it needs to be. Indeed there is a danger with new techniques that reliability may suffer: in my view this summarizes the differences between American and Russian experiments.

Because of the unknown factors, it is not possible now to specify in great detail the vehicles that will be required.

The programme has therefore been seen as a number of phases, and for each phase as assessment has been made of the potential payloads that could be placed in four or five orbits. Underlying the analysis has been the assumption that 1 ton is a useful payload, half a ton somewhat marginal, and 2 tons or more a princely payload suitable only for special experiments. These weights have been criticized in scientific circles as excessive, and it is certainly true that a considerable number of instruments would be needed to make up a 1-ton load. Mention is therefore made of smaller vehicles which would be useful for launching small instruments. Nevertheless, not all the experiments will require the trajectories considered here, and some of the desirable objectives will be only just attainable. For flexibility to meet these requirements, the launcher must have excess capability. Small differences from the assumed values for structure and engine weights and specific impulse will then be not nearly so critical. In any case it is a wise precaution to plan for a vehicle that is too large, so as to avoid building one that proves in practice to be incapable of doing what it was built for.

It should also be noted that there are dear ways as well as cheap in financing development. Taking rocket engines as typical examples, expense is kept to a minimum by spending time during the initial project stage in careful examination of the real requirements and in careful analysis of the suitability of the proposals. Fundamental experiments and feasibility studies also must be carried out well in advance of possible applications so that there is time for the significance of the results to be properly understood. Any unresolved issues at the start of the development programme are likely to result in the design, manufacture and development of unsuitable machinery and a late change can invalidate much costly experience.

Once it is decided to go ahead with the design and development of the engine, however, time is the one commodity which should not be provided. Desultory development is expensive and ineffective, and the best results are obtained when the organization is urgent and enthusiastic.

To keep the development teams together, the ideal programme will require the consecutive development of items of equipment, none of which is so large that it cannot be handled in reasonable time. Thus there is probably an optimum rate of development of the space programme, and this should be investigated.

Fixed Resources

The British Commonwealth has one asset for a space programme possessed by no other single community in the world: its scatter. It is hardly possible to plot a great circle on the globe which does not pass close to a number of potential sites for Commonwealth tracking stations. Moreover, member nations control territories at nearly every latitude between 50° south and the North Pole, with an area of Antarctica thrown in for good measure.

For the present purposes of a space programme there are three sites of particular interest. The first, at approximately 55° north, is the Rocket Establishment built by the Ministry of Works on Spadeadam Waste, some 20 miles north-east of Carlisle. This Establishment, which is managed for the Ministry of Aviation by Rolls Royce Ltd, has rocket engine test beds and missile test stands for Blue Streak. Two of the missile stands are similar to the launcher pads built for Blue Streak at Woomera, Australia, and could presumably be used for launching vehicles from this country. The only possible trajectory, however, would be roughly south-west down the Solway Firth, and even so the proximity of Carlisle, Annan and a number of smaller towns would make launching an excessively hazardous activity.

The same orbit and many others could be obtained if the vehicles were launched from the rocket range at Woomera in Southern Australia. This range is owned and operated by the Department of Defence, Australia, and lies at approxiamately 30° south at the south-easterly edge of a vast desert, which provides an excellent catchment area for spent stages. Launching may be made with trajectories at any angle between due north and nearly due west, and hence satellites could orbit in planes inclined at between 90° and 30° to the equator, all having opposite rotation to the Earth. Easterly launchings, taking advantage of the Earth's rotation (which is equivalent at Woomera to 1300 ft./sec.) are not possible and it would thus be awkward and inefficient to launch a "stationary" satellite (orbiting once in 24 hr.)

The third site does not appear to have been seriously considered, probably on account of the expense of the fixed installation necessary. It is on the top of Mount Kenya. Situated on the equator and rising to a height of over 17,000 ft. this dormant volcano seems to be the ideal launching site for interplanetary probes and other difficult launchings. The Indian Ocean lies some 380 miles east of it and beyond that lie a number of islands under Commonwealth control and suitable for tracking stations. Singapore is directly in line some 4000 miles away. Between Mount Kenya and the coast there is an area which, though populated, is not apparently heavily populated, part of this area lying in Somalia.

The only rival sites are near Quito in the Andes, either in Ecuador or Colombia, and about 150 miles from the west coast of South America. Peaks in this vicinity (also volcanic) rise to about 18,000 ft. Easterly trajectories would traverse the whole of the Amazon basin, one of the few areas of the world still to be explored, and while this might be a good catchment area, tracking during the important intial stages would be very difficult, especially as some of the natives appear to be hostile.

Either of these sites would have five advantages over Woomera:—

(1) An equatorial trajectory makes it easier to place satellites into orbit in the plane of the ecliptic: and the easterly launch makes it possible to launch "stationary" satellites efficiently.

(2) An equatorial launch provides the maximum initial velocity (1500 ft./sec.) for a vehicle launched in an easterly direction.

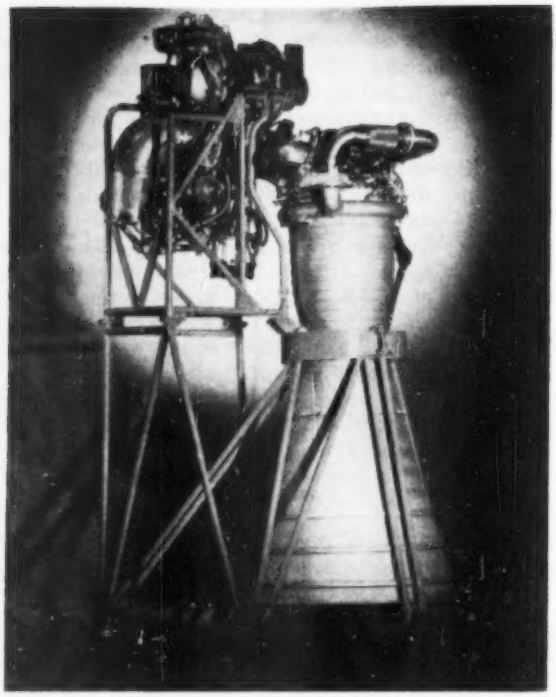
(3) The low atmospheric pressure at 17,000 ft. causes the specific impulse of the rocket engine to be increased at launch by about 6%.

(4) The improvement in specific impulse enables an increased launch weight to be used without corresponding increase in engine weight, hence increasing the mass ratio of the vehicle by nearly the same amount.

(5) The low density of the atmosphere results in lower aerodynamic drag during the initial phases of the launch.

Compared with an equatorial sea level site, the gain could be worth about 1500 ft./sec. Although this does not sound very high it corresponds to an increase in payload of between 20 and 30%, depending on the conditions. For the launch of a manned expedition to the Moon this could be worth £5 million per shot. The only known technical disadvantage is that the launch trajectory passes through the deepest section of the Van Allen belt.

In addition to the vertical test beds and missile stands at Spadeadam and Woomera, there are vertical rocket engine test beds at the Rocket Propulsion Establishment, Westcott, near Aylesbury, and at Ansty, Coventry, where the Rocket Division of Bristol Siddeley Engines Ltd. is housed. The Saunders Roe Division of Westland Aircraft Ltd. also has missile firing stands for Black Knight at High Down, overlooking the Needles on the Isle of Wight.



Rolls Royce RZ2 rocket engine of 135,000 lb. s.t.; two such units are installed in Blue Streak.

Rolls Royce, Ltd.

Propulsion Resources

At the present time there are known to be rocket engines made in this country which have independent combustion chambers with low moments of inertia about their centres of gravity, and which are therefore suitable for a space programme.

By far the largest of these is the Rolls Royce RZ series of engines originally developed under a Rocketdyne licence for the De Havilland Blue Streak. In Blue Streak there are two identical engines each having its own turbo-pump unit and its own combustion chamber. The combustion chamber is mounted on a pivot at its forward end and rocked by jacks to provide control of the thrust axis for steering the vehicle, and any plural number of these engines could be used without modification for future vehicles. The thrust of the RZ2 engine is quoted as 135,000 lb. at sea level and the propellents are liquid oxygen and kerosine—the cheapest of all combinations, and in performance one of the best.

The other available engine burns HTP (hydrogen peroxide) with kerosine.

It is the Bristol Siddeley Gamma Mk. 201 engine which is also suitable for a space programme as it is. This has four pivoted combustion chambers, the maximum thrust at sea level being 16,000 lb. rising *in vacuo* to just under 19,000 lb. This is the engine which has so far launched successfully all eight of the R.A.E./Saunders Roe Black Knight re-entry research vehicles.

Propellents

The full equation for the specific impulse of a rocket combustion chamber at any altitude greater than that for which it is correctly designed is shown below:

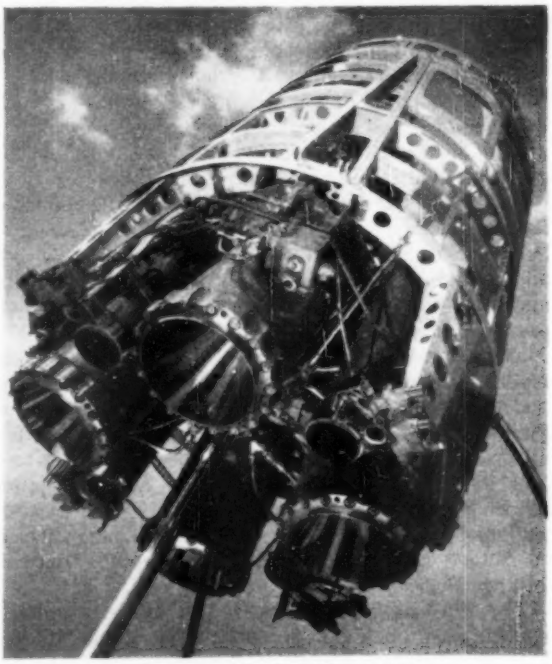
$$I = \frac{\theta}{\dot{w}} = \frac{1}{g}\sqrt{\frac{g\gamma R_u T_c}{\bar{m}}}\left[\sqrt{\left(\frac{2}{\gamma-1}\right)\left[1-\left(\frac{1}{r_e}\right)^{\frac{\gamma-1}{\gamma}}\right]}+\frac{\left(\frac{1}{r_e}-\frac{1}{r_a}\right)\frac{1}{\gamma}\left(r_e\right)^{\frac{1}{\gamma}}}{\sqrt{\left(\frac{2}{\gamma-1}\right)\left[1-\left(\frac{1}{r_e}\right)^{\frac{\gamma-1}{\gamma}}\right]}}\right]$$

Where I = specific impulse — lb sec/lb
θ = thrust — lb
$\dot{w}$ = mass flow of propellants — lb/sec
g = gravitational constant
γ = ratio of specific heats of exhaust gases — C_p/C_v
R_u = universal gas constant — ft. lb/lb/°K
T_c = absolute combustion temperature — °K
$\bar{m}$ = mean molecular weight of exhaust gases
r_e = design pressure ratio of expansion nozzle
r_a = ratio of combustion pressure to ambient atmospheric pressure

The points to note about this are that the specific impulse is high if:

the temperature is high;
the mean molecular weight is low;
the design expansion ratio is high;
the ambient pressure is low.

What is not immediately apparent from this equation is that the specific impulse is high if γ, the ratio of specific heats, is high. A high value for this indicates that the actual specific heats at constant pressure and constant volume are low, and in turn this means that the molecule has little internal energy, so that the heat



Bristol Siddeley Gamma Mk. 201 rocket engine.

Bristol Siddeley.

is more readily converted into molecular kinetic energy. Since the aim of the expansion process is to convert the heat into translational kinetic energy, this is obviously desirable.

Consideration of the equation indicates that for a given specific impulse, the temperature is likely to be lower if the mean molecular weight of the exhaust gases is lower, which has a hidden advantage because the amount of heat released during combustion is temperature dependent. At the pressures normally used, there is virtually no dissociation of the combustion gases if these are at 2000° K.; if the actual flame temperature is 2700° K., dissociation has reduced the heat released by about a tenth; and if the actual flame temperature is 3400° K. it has reduced the heat released by about a third. Thus a lower molecular weight permits a higher percentage of the available energy to be converted into kinetic energy.

With most propellents, variation of these values is usually fairly marginal. The combustion temperature is usually between 2700° K. and 3400° K., the mean molecular weight between 19 and 25 and the ratio of specific heats between 1·15 and 1·25. When selecting propellents for a space programme, however, there is one fuel which demands very serious consideration — it is hydrogen.

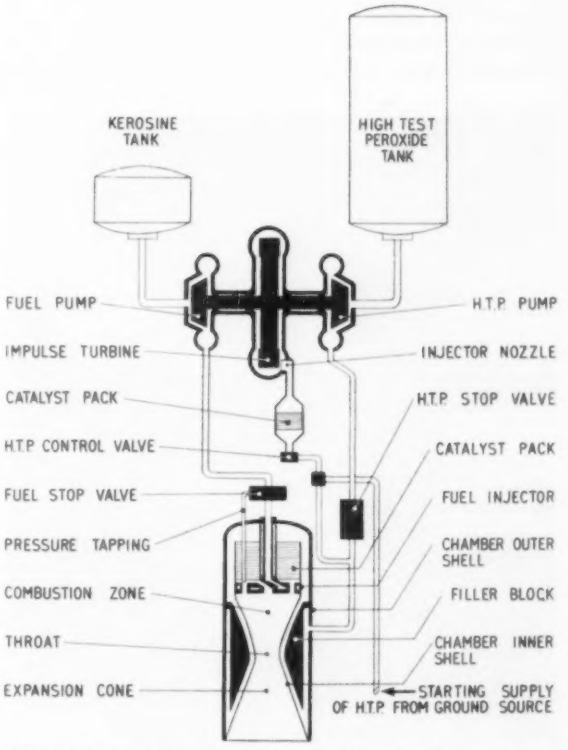
Liquid Hydrogen

Hydrogen is the least dense of all gases, which for our purpose is its main advantage, but when liquified it is also the least dense of all liquids, which is its main disadvantage. The density of liquid hydrogen is in fact only about 4⅓ lb./cu. ft.—less than half the density of liquid helium and only 7% of the density of water. As a liquid it has two states, *ortho-* (or normal) and *para*-hydrogen. The boiling point of *para*-hydrogen is an eighth of a degree C. lower than *ortho*-hydrogen, being 20·28° K. at a pressure of 760 mm. of mercury. In equilibrium at the boiling point, *para*-hydrogen comprises about 98% of the bulk of the liquid, but when the gas is refrigerated normal liquid hydrogen is formed first, and transforms itself subsequently into *para*-hydrogen with release of heat. This is most undesirable because it means that the evaporation rate is greater than would be expected, and considerable efforts have therefore been made to find means of producing *para*-hydrogen initially. Present information is that this problem has been successfully overcome by catalysis, and that *para*-hydrogen could be produced in bulk. About the cost there appears to be some argument: one American source quotes $7 per lb. (£5600 per ton), whereas other quotations have been as low as £250 per ton. The latter sound more probable.

Gaseous hydrogen is the ideal working fluid for a rocket engine. It has a molecular weight of 2, and the ratio of its specific heats is 1·41 at room temperatures falling to 1·30 at 3000° K. If it were possible without losing additional mass, to heat the pure hydrogen to 3000° K., the specific impulse theoretically attainable in space with a 1000:1 expansion nozzle would be 975 lb. sec./lb. Plasma jet rockets which produce temperatures of 5000° K. or more are expected to give specific impulses exceeding 1500 lb. sec./lb. These temperatures are attainable if a nuclear reactor is used as the primary source of heat. For chemical propulsion, however, the hydrogen must be heated by burning some of it with an oxidant. As this process considerably modifies the desirable properties of the working fluid, the oxidant selected should preferably be that which gives the greatest release of heat in the reaction.

COMPARISON OF PROPELLENT COMBINATIONS FOR LAUNCHING SPACE VEHICLES

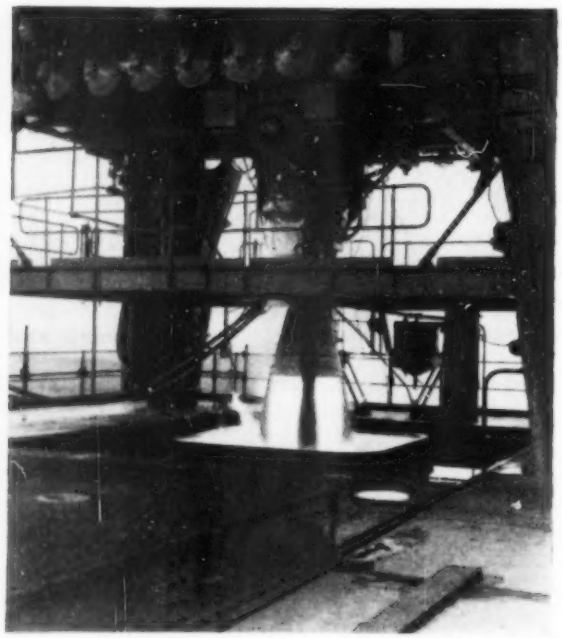
Propellents	$(Ve)^2$ Sea Level $\left(\frac{ft}{sec}\right)^2$	$(Ve)^2$ *in vacuo* $\left(\frac{ft}{sec}\right)^2$	Density lb/ft³	Cost Per Ton £
85% H.T.P./Kerosine	49×10^6	71×10^6	80	150
LO_2/Kerosine	61×10^6	87×10^6	63	14
LO_2/LH_2	112×10^6	152×10^6	16	170



H.T.P./kerosine rocket engine system based on the Bristol Siddeley Gamma 201 engine. *Bristol Siddeley.*

Liquid Fluorine

As far as is generally known, the most energetic reagent with hydrogen is fluorine. Loosely described as an oxidant, this is a canary yellow halogen with a molecular weight of 38, and it combines with hydrogen to form hydrogen fluoride with a heat release of 3,370 C.H.U./lb. of propellents. This compares with water which when formed by combustion of hydrogen and oxygen gives a heat release of 3,210 C.H.U./lb. of propellents. Thus liquid fluorine releases 5% more energy than liquid oxygen, which it closely resembles in respect of boiling point and density, but with hydrogen the benefit is rather greater because, being a diatomic molecule, hydrofluoric acid has a lower specific heat than steam, less oxidant is needed and a higher gas temperature is obtained: there is in fact about 5% improvement in specific impulse. Rocket engineers who have used it consider fluorine to be a practicable oxidant provided stringent safety precautions are adopted. It is, however, one of the most toxic of all rocket propellents: problems of handling, and dealing with spillage are very real, and as the exhaust from the engine is equally toxic there are severe test bed problems. These hazards do not appear to be compatible with an inexpensive satellite launcher and would not be justified in the intial phases of the programme. As the objectives approach the limit of practicability, nevertheless, there may be good arguments for using fluorine in the top one or two stages. The differences between oxygen/hydrogen and fluorine/hydrogen engines seem to be fairly small, and it would be preferable to start by using liquid oxygen, and to adapt these engines to use fluorine when required. The differences would be related to some of the materials used, to the necessity (which does not exist with oxygen) of sealing in the fluorine completely, and of small modifications of the drillings in the oxidant injector. Since the combustion chamber would be cooled with hydrogen in either case this expensive component would hardly be affected.



Rolls Royce RZ2 rocket engine being test-fired at Spadeadam.
Rolls Royce, Ltd.

Liquid Oxygen

A great deal is known in this country about the use of liquid oxygen. The rocket engine team at Bristol Siddeley developed both the Snarler and the Screamer rocket engines *ab initio* to use it, and Rolls Royce have been using enormous quantities in the further development of their RZ2 rocket engine. It is a clear liquid, slightly bluish when seen in bulk, and at its boiling point of 90·2°K. it has a density of 70·51 lb./ft³. It is of course obtained by fractional distillation of liquid air, and is one of the cheapest rocket propellents obtainable, though is is difficult to quote exact prices because these depend on the efficiency of the plant used and on the distances over which the liquid has to be transported.

Liquid oxygen is a pleasant oxidant to handle because it is not toxic and spillage evaporates quickly. Although safety precautions must be observed it is in fact fairly difficult to get accidental reactions between liquid oxygen and fuels because of its low temperature; but once started, reactions are fierce. Severe frostbite results from prolonged contact with liquid oxygen, but small splashes are not hazardous, provided clothes are not impregnated with strong concentrations of oxygen in proximity to flames.

Probably the cheapest propellent combination of all is liquid oxygen and kerosine, and as this has a fairly high performance by comparison with combinations other than those with hydrogen, it seems to be ideal for the largest stage of any vehicle.

Hydrogen Peroxide

One other oxidant which must be discussed is hydrogen peroxide. Whilst this may be used for the middle and top stages of the Blue Streak satellite launcher, it does not give the best performance. However, availability of suitable propulsion makes it an economically attractive choice initially. Later development of these stages to use liquid oxygen and liquid hydrogen would improve the performance of the launcher, as we shall see.

However, there are some possible objectives of a space programme to the attainment of which hydrogen peroxide/kerosine propulsion can make a most valuable contribution. Although not the most storable of oxidants, H.T.P. is reasonably storable over a period of a month or two, and its use permits of exceedingly simple engine systems.

It is a liquid rather like flat soda water in appearance, with occasional bubbles of oxygen rising to the surface from slow decomposition. 85% hydrogen peroxide

decomposes into 40% oxygen and 60% water, the latter effecting a useful reduction in the mean molecular weight of the exhaust gases when the oxygen is burnt with kerosine. Hydrogen peroxide can be decomposed in a catalyst pack consisting of silver-plated nickel gauze, and with a temperature of about 900°K. the gases constitute a useful working fluid for driving the turbine. Catalytic decomposition also provides for good starting characteristics in the combustion chamber, because kerosine ignites spontaneously with the hot gases, and they are probably helpful in maintaining high combustion efficiency when the engine thrust is reduced to a small fraction of full thrust.

The density of H.T.P. is 85 lb./ft³, and it freezes at a temperature around 255°K., boiling at 410°K. There are some hazards associated with its use, and protective clothing is necessary.

Liquid Oxygen/Liquid Hydrogen Combinations

We must now consider the combinations of liquid oxygen and liquid hydrogen in more detail. If they react in stoicheiometric ratio (chemically correct ratio) the combustion temperature is 3500°K., the ratio of specific heats is 1·24 and the mean molecular weight is 16. Equivalent values for liquid oxygen/kerosine would be 3400°K., 1·22 and 23. Thus use of hydrogen results in the release of nearly 50% more energy than use of kerosine, and the specific impulse is just over 20% higher. As we have seen, however, hydrogen is the ideal working fluid, whereas steam is not, and the maximum specific impulse is obtained when only a part of the hydrogen—about 45%—is burnt with oxygen to heat the gas mixture to 2650°K. The mean molecular weight is then 9, and the ratio of the specific heats is 1·28. There are however a number of other considerations which affect this choice of mixture ratio.

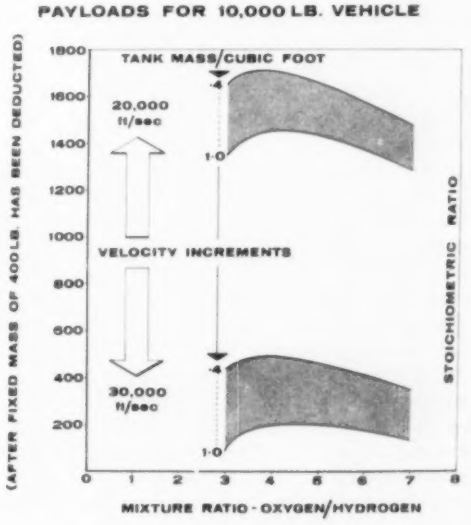
One of these is the tank mass. A diagram shows the payloads that can be given velocity increments of 20,000 and 30,000 ft./sec. by a vehicle having an initial mass of 10,000 lb. and a final mass of 400 lb. plus the mass of the tank. The abscissa is the mass mixture ratio of the propellents. The top curves represent the best that could be achieved with currently available steels and light alloys; the bottom curves may represent more realistic values, although there is obviously such a great benefit resulting from the use of the light tanks that every effort will be made to achieve them. If they were achieved it might be theoretically possible to put small payloads suitable for research purposes into orbit with a single stage, but the tolerance for errors would be so small that the attempt would only be justified if the vehicle had already been developed for another purpose. Thus with a liquid oxygen/liquid hydrogen engine the chance of successfully launching a small payload into a 300-mile circular orbit with a single stage is probably just too marginal.

Bottom Stage Propulsion

This statement that a single-stage vehicle could almost launch a satellite if the fuel were hydrogen, is apparently inconsistent with the earlier comment that kerosine would probably be used for the bottom stage. This inconsistency is due to an assumption that size is likely to be as serious a consideration as weight in the choice of a vehicle. Consideration of three alternative two-stage vehicles with different fuels—both hydrogen, one kerosine and one hydrogen, and both kerosine—makes it evident that the vehicle with kerosine for the bottom stage and hydrogen for the top stage is the smallest. In this case the mass ratio of the first stage is 3 and that of the second is 5. If both stages used hydrogen, the mass ratio of each stage would be about 3·3, the launch weight would be reduced by a quarter, but the gross volume would be increased by a half.

Alternatively if both stages used kerosine, the mass ratio of each stage would be 5·9, the gross volume would again be increased by a half but the launch weight would be doubled. This argument shows that only the bottom stage should use kerosine; all the other stages should use hydrogen.

These values are dependent to some extent on the assumptions made about the structural efficiencies of the vehicles, but the comparative ratios are so large that the conclusions will not be affected. It is interesting to note, by way of confirmation, that the N.A.S.A. "Saturn" launching vehicle has liquid oxygen/kerosine propulsion for the bottom stage and liquid oxygen/liquid hydrogen propulsion for the other three stages.



Blue Streak servicing tower. *Rolls Royce, Ltd.*

A British Space Programme

Having considered some of the more important conditions which must be laid on an economic programme, the probable development of the British space programme may be considered in some detail. I see it as a number of phases, each of which introduces a change of propulsion for a single stage, or the provision of a fixed installation. For each phase there may be a variety of payloads, and it may be expedient in practice to have more than one variant of the rocket engine, but as this would be more a rearrangement than full scale new development further mention of it need not be made.

To clarify the argument, a system of stage identification is helpful. Let us say that stages propelled by liquid oxygen/liquid hydrogen are OH; liquid oxygen/kerosine, OK; and hydrogen peroxide/kerosine, PK. The size of the stage may be indicated by the position it would have in the launcher, and since the top stage is the same size in all phases, call this 1. Then Blue Streak is OK3, the modified Black Knight is PK2 and so on.

The first phase proposed consists of OK3, PK2 and PK1. Mr. E. C. Cornford[1] has already outlined its potential in some detail; he says that it should be capable of placing a payload of 1800 lb. in a precision orbit at an altitude of 300 miles, or of placing a payload of up to 200 lb. in a highly eccentric orbit with an apogee of 100,000 miles. By the same token it could give escape velocity to a payload of nearly 50 lb.

The second phase would involve no more than the replacement of PK1 by a new stage OH1. This would make little difference to the close Earth orbit, the payload rising to just over 1 ton. For the orbit with 100,000 mile apogee, however, the orbital weight would be more than doubled; that is, the payload would be multiplied by a factor of three or four, even allowing for the greater specific weight of liquid hydrogen tanks. Escape velocity could be given to a payload of about 250 lb.

These figures disguise a very important feature of this phase, which is that there are now two vehicles capable of launching satellites. Placed on top of a standard Black Knight and launched from the Black Knight launcher pad, this top stage could carry a payload of about 100 lb. into the 300-mile orbit. This is admittedly marginal, but is provides an economic means of launching small scientific instruments, and meets the objections mentioned earlier. Even if the Government decides not to embark on the Blue Streak satellite launcher, we could still use British launchers for some of our space research, by providing just this small stage.

It is the third phase, however, which introduces the really exciting possibilities. This is the replacement of PK2 by a new stage OH2. With a top stage, the payload in the 300-mile orbit would be about 3 tons which should be sufficient for experiments leading up to manned re-entry. The payload in the orbit with 100,000 mile apogee would be about $\frac{3}{4}$ ton, and escape velocity could be given to a load of several hundred pounds.

If the payload were provided with the propulsion unit of PK1 to retard it, soft landing of perhaps 200 lb. of instruments could be made on the Moon.

Even more exciting is the fact that stages OK3 and OH2 by themselves would be capable of placing 1 ton in orbit at an altitude of 300 miles, which means that a space station 10 ft. in diameter and over 40 ft. long—stage OH2, in fact—could be placed in an orbit where it would remain for several years. The insulated tanks, with a capacity of about 3000 ft.^{3}, could be made suitable before launch for subsequent habitation and provisioned with men and materials by three-stage vehicles. A manned observatory would be a practical proposition.

Is this too far fetched? It may seem so now, but in 10 or 15 years time it could well be practicable if we wanted to do it.

Exploitation of this phase could occupy us for a long time, but it should be noted that there are two more phases before we could consider placing men on the Moon. The fourth phase requires the replacement of OK3 by OH3, requires a new stage OK4 and requires new launcher facilities. The launch weight would be around $1\frac{1}{2}$ million lb. (700 tons) and as Britain would by this time have made its mark, it could afford to buy suitable lower stages from America, where they are already under development. The cost of providing the new launcher pads would be sufficient development expenditure for 2 or 3 years, and this would be the time to re-examine the geographical location of the launcher site.

The fifth phase is an exact repetition of the fourth, but on a scale five or six times as great, and the same policy is recommended.

You may be surprised that purchase of American stages is advocated for these last two phases. I am not convinced that the technological benefits to be derived from developing these large rocket engines and tank structures are commensurate with the costs; in any case we would be decades late, and we lack sufficiently large

barren areas in this country to permit the testing of them.

Even if we would not be able to use British propulsion to get our Moon voyagers off the ground, at least we could do so to land them on the Moon and bring them back. The Gamma engine seems to be quite suitable, and with the background it would have had by that time we would all be confident of their safety.

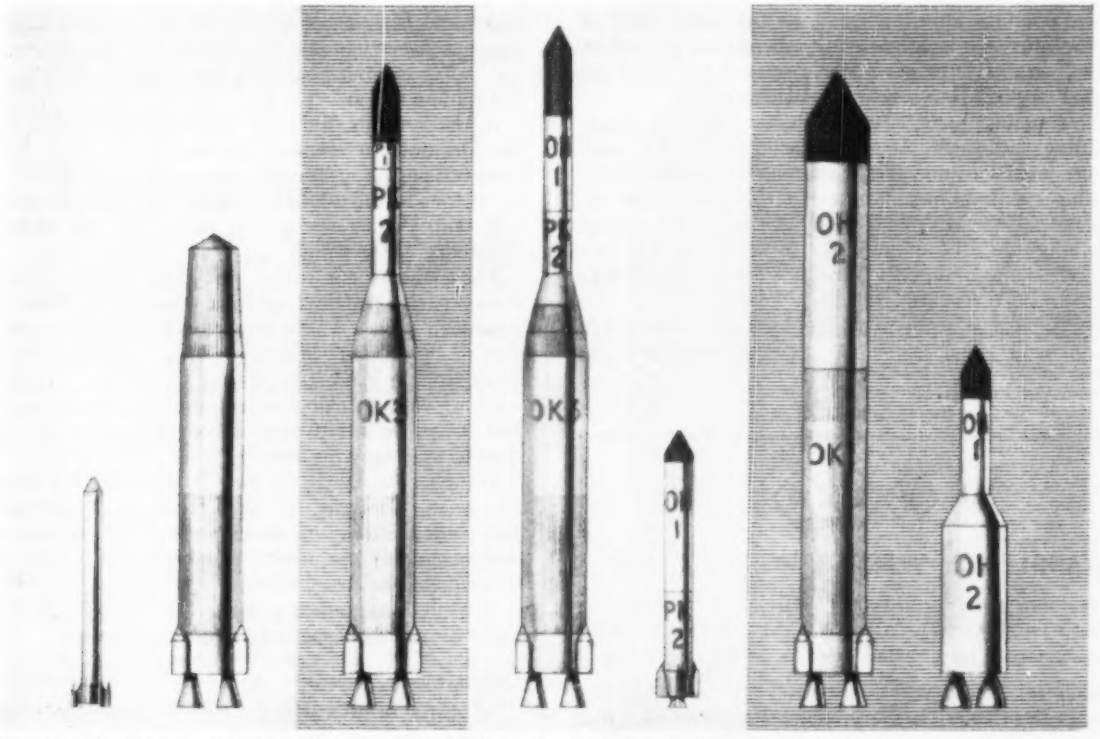
We have said nothing of space-engines, of guidance and tracking, of instrumentation and telemetry, nor of any other of the equipment which will be developed as the programme proceeds. We need not regret this, because these are as much the justification of the programme as the scientific data collected. We intend to enter the space programme because it will provide incentives for advanced technological developments, and we must not be afraid to seize the opportunities gratefully.

Economics

It is desirable, for the sake of completeness, to have some idea of the probable cost of a programme such as the one I have described here. There are, however, two difficulties: not only do considerations of national security encourage reticence in these matters, the firms engaged in the work also have private reasons for keeping the details closely guarded; and I have no reliable information. Some estimate can, however, be made on the basis of a few scraps of information available.

Black Knight was said to have cost a total of £5 million up to the end of 1958, that is after 3 years' development had led to the successful first launching. The cost of Blue Streak to date has been variously quoted at from £60 million to £100 million. American journals have quoted sums of £90 to £125 million for the Mercury "man in space" programme. The *Daily Telegraph* has suggested that the Blue Streak satellite launcher would cost £15 million a year to develop, but the duration of the development has not been quoted. The figures are all of doubtful validity and conclusions drawn from them cannot be taken as precise. They do, however, appear to be reasonably consistent, as we shall see.

Considering first the Blue Streak satellite launcher—phase 1 of my argument—Black Knight exists, but requires a new structure and a number of other changes. It might be reasonable to assume £1 to £2 million for the conversion. Blue Streak has about seventeen times the thrust of Black Knight: if developed for the same role as the latter, therefore, the total development cost might have been seventeen times as high: this is probably excessive, but it makes allowance for the fact that more extensive facilities might have been provisioned for Blue Streak in its original role. If we assume that two thirds of what has been spent on Blue Streak has relevance to



Proposed development programme for Blue Streak (see text). Standard Black Knight and Blue Streak are indicated at extreme left.

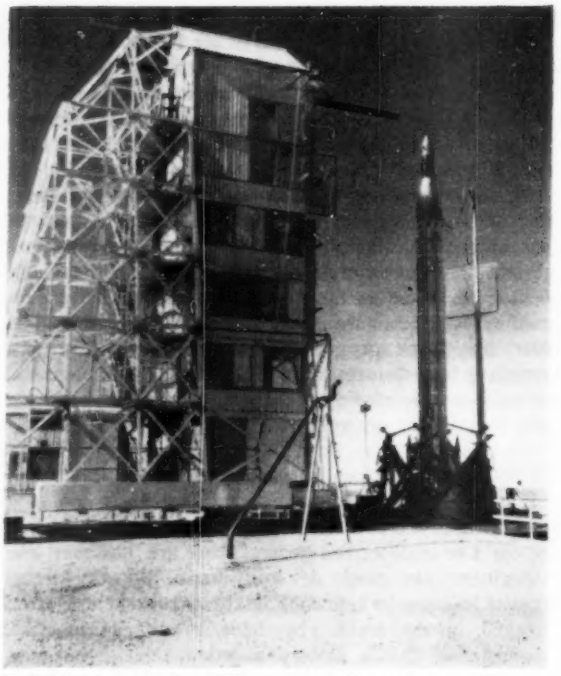
the satellite launcher programme, the additional development cost could be between £18 million and £45 million. For argument's sake, say £32 million. If we allow as much for the top stage as was originally required for Black Knight, the total development cost of phase 1 would, on this analysis, come to about £38 million. At the rate of expenditure suggested by the *Daily Telegraph* this would result in a first launch in the middle of 1963. For some reason, the *Daily Telegraph* poured scorn on their estimate of the expenditure, quoting an unnamed authority for the remark that for £15 million a year one could not launch a tube of toothpaste into orbit.

Development costs would presumably continue on this launcher even after the first successful firings, as they do with all other projects in current production. Let us suppose that in the subsequent year they are half the maximum rate, the next year one-third, and so on. The unit costs of vehicles launched are more difficult to guess. They might cost anything from £20 to £50 per 1 lb. fixed weight, or perhaps even more depending on the manufacturing difficulty, a range of about £300,000 to £700,000. Let us take a round value of £1 million to include launching costs.

On this basis Britain could launch in the next 6 years a dozen payloads into the 300-mile orbit, a total of about 10 tons, for an additional cost in the region of £70 million. An American journal has quoted present costs of launching satellites into orbit at about $10,000 a lb. —corresponding almost exactly to the same total of £70 million. On the basis of information published, "Scout"—called "the poor man's satellite"—would not put that payload into orbit much more cheaply.

Allowing in phase 2 for re-engining the top stage, providing additional launching facilities for the small satellite launcher and for the alternative versions of the two stages, a development cost of £10 million would be, if anything, excessive. Without exceeding an overall expenditure of £14 million a year therefore the first flight of this new launcher vehicle could, if desired, take place towards the end of 1966.

The third phase might be more expensive—say £20 million as a rough estimate. Even allowing for the additional expense of developing the manned capsule, manned re-entry would be possible for Britain early in the 1970's without exceeding the overall expenditure of £14 million a year.



Black Knight on its launching stand at Woomera.
Bristol Siddeley.

In other words, for £140 million Britain could be on the threshold of manned exploration of space, having launched in the meantime perhaps the equivalent of 25 to 30 tons in the 300-mile orbit. This figure compares well with the figures quoted earlier for the N.A.S.A. "Mercury" programme.

The agreement is rather too good, in fact: I would have expected British development costs to be lower than American costs—which is certainly believed to be the case in the aircraft industry. This is because development work is essentially related to the cost of labour, working without elaborate equipment; and the salaries and wages in the United States appear to be about double what they are here.

However, in Britain it may be necessary to develop equipment specially for this programme, whereas in the United States the development cost of equivalent equipment may be spread over a number of programmes, so reducing the cost to each.

It would be pointless to discuss the costs of the fourth and fifth phases of my proposed programme.

Conclusions

By virtue of its scatter the British Commonwealth has as much need as any other single community for the practical benefits of a space programme, has more

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natural features suitable for launching sites than most, and sites for tracking stations on nearly any desired great circle. However, the realities of the Commonwealth make it inevitable that Britain will have to bear the brunt of the cost.

The present is a good time to begin a space programme because suitable technical teams exist and are not distracted by other commitments, and suitable facilities are already built. Taking for granted—as I do—that a British space programme is inevitable, an immediate start would result in considerable economies.

The Blue Streak satellite launcher is a useful vehicle in its own right, and provides a splendid basis for further development. Without significant alteration to the bottom stage or the launcher pads, and merely by the development of two small liquid oxygen/liquid hydrogen rocket engines and tank systems, the programme could be carried to the stage of launching manned space stations.

Black Knight, combined with a stage propelled by the smaller of these two engines, would provide an excellent additional launcher for placing small payloads in near-Earth orbits, while for slightly more difficult tasks, a vehicle consisting of both the liquid oxygen/liquid hydrogen stages could be launched from the Blue Streak launcher pads.

With the provision of new launcher pads and additional bottom stages the programme could be extended well into the future, to the phase of manned exploration of the Moon without any obvious incompatibility of the earlier equipment. It is evident, therefore, that Britain is singularly fortunate in its resources, and would be irresponsible to squander them.

Whilst I do not claim that this is the only possible way of developing the satellite launcher, what I have endeavoured to show is that any start made today on a space programme should envisage the possibility of further development along similar lines.

A programme incapable of further development should not be contemplated as the development costs could not be amortized over a sufficiently large number of satellites. As we have seen, the proposed Blue Streak satellite launcher fulfills all requirements admirably.

The programmes will throw up requirements for space engines which will provide an incentive, otherwise lacking, for advanced propulsion technology; instrumentation and guidance will be advanced and the scientific returns from space research will help to provide the basis on which future prosperity of the Commonwealth will be built. For a very small fraction of the National budget a space programme could be sustained which would be a visible symbol of British competence to the rest of the world, and a source of inspiration for our own people. Let us do it.

ACKNOWLEDGEMENTS

I wish to thank the Ministry of Aviation and Bristol Siddeley Engines, Ltd., for permission to present this lecture, but the opinions expressed are my own.

REFERENCE

1. Cornford, E. C., "A British Space Booster," *The Aeroplane and Astronautics*, Aug. 12, 1960.

Correspondence

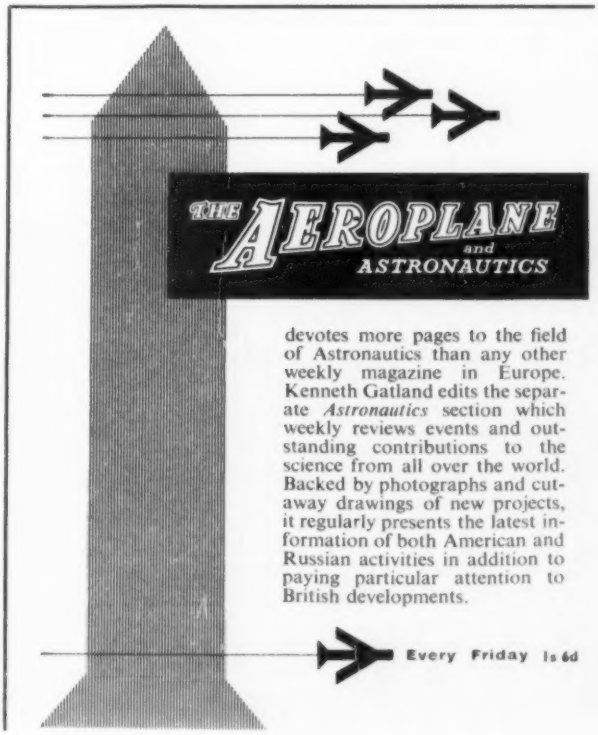
SIR,—Quite often in modern astronautical literature it is stated that Titan, sixth moon of Saturn, would be an excellent refuelling base for atomic rockets because of its methane atmosphere. Ganymede, third of the Galilean satellites of Jupiter, is not very much smaller than Titan, and its escape velocity is not much lower than that of Titan. Yet most astronomical books state bluntly that Ganymede has no atmosphere at all. In view of the above facts, this does not seem quite reasonable.

In addition, Triton of Neptune is somewhat smaller than Ganymede and has an escape velocity about equal to those of Triton and Ganymede. Yet traces of methane have been detected on Triton by some observers. This implies that Triton also has an atmosphere. If this is so, why should Ganymede be different? The greater proximity of Ganymede to the Sun would probably not raise the temperature of Ganymede by a sufficient amount to cause the atmosphere (if one does exist) to escape.

For these reasons, it seems that Ganymede might conceivably have an atmosphere and could be used as a refuelling base by expeditions to Jupiter. This last could also be true in the case of Triton and Neptune.

I would be most interested in the views of any of the readers of *Spaceflight* on the possibility of an atmosphere on Ganymede.

WILLIAM J. WESTBROOKE.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B.I.S. at "Biggin"

One of the most popular of the many interesting exhibits at last year's Battle of Britain Open Day at Biggin Hill was a stand organized by the B.I.S. Lest this appears an undue exaggeration, at one time people around the stand were so numerous that the writer, who had momentarily left the main counter, had to wait nearly 10 min. before the crowd had thinned sufficiently to enable him to return.

The centre of attraction was undoubtedly a series of demonstrations showing some effects of very low temperatures. Liquid nitrogen was splashed alarmingly on the floor, much to the delight of the onlookers. Both young and old were fascinated by the lengths of rubber tubing, bananas and plums which, pliable and soft one minute were, after immersion in the super-cold liquid, shown to be as brittle as glass.

Nearby, two high-powered microscopes enabled visitors to examine free cells of chlorella, that diminutive plant which one day may help solve the food problem on long interplanetary journeys. Accompanying notices explained briefly the principle of synthesis; how green plants, when illuminated by bright sunlight, take up carbon dioxide and give off oxygen through their leaves.

Another item of great interest was a full-size model of the American satellite Explorer 6. Being able to examine this closely and even to fold and extend its four solar-cell carrying vanes, imparted a feeling of awe when one realized that the original had transmitted the first ever picture from space and that a similar device (Pioneer 5) had only a few months previously transmitted data to the Earth from the incredible distance of 22½ million miles.

Other exhibits included a Napier Scorpion rocket engine, Bristol Siddeley Stentor engine, a replica of Sputnik 1, and models of the Vanguard, Explorer 1 and Atlas satellite boosters. Along the background were scale models of the planets and a series of excellent drawings loaned by the Society's Midland branch. —M. F. A.

Review

Guide to Rockets, Missiles, and Satellites. By Homer E. Newell, Jr., McGraw-Hill Book Co., $2.50.

Although the preface explains that this book is "intended to provide the general reader with a brief review of some of the high-speed weapons and vehicles that are either in existence or under development," it is not easy to visualize the class of reader at which it is aimed.

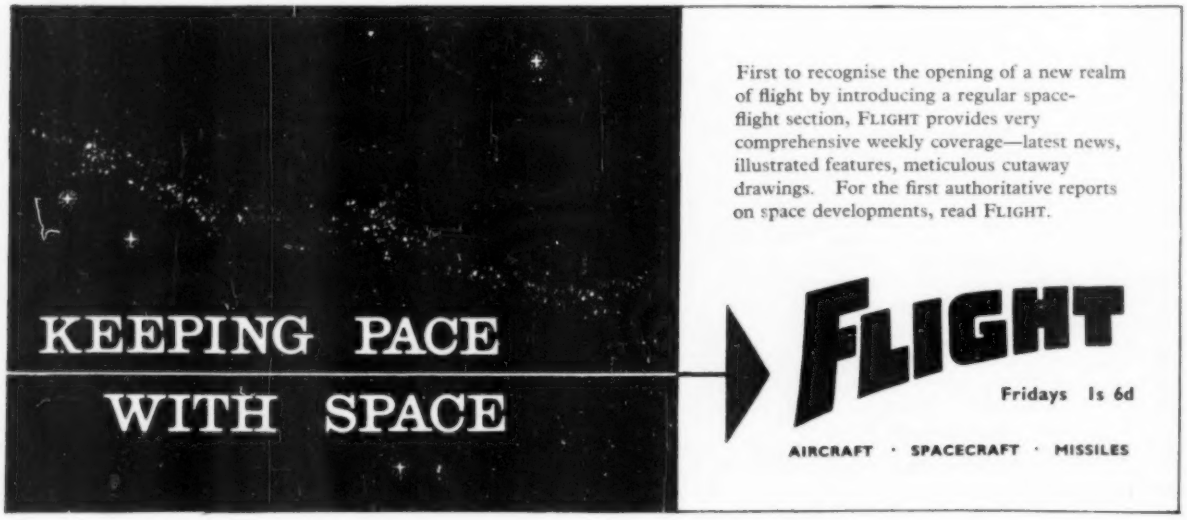
Nearly 80 rockets and missiles are illustrated and described, but the coverage of many of these is so brief as to be almost valueless. For example, the Bull Goose insert comprises "Diversionary missile. U.S. Air Force. Used to deceive the enemy"; the Pershing: "Surface-to-surface missile. Army," and Genie: "Air-to-air missile. U.S. Air Force." Even the mighty Atlas is described in less than 100 words. Thus, the book is not detailed enough for the serious student, and yet seems unweildy for those who want a simple "catalogue" of current missiles. For these a much more compact book could be produced.

Again, although the preface stresses the book concentrates on U.S. vehicles and weapons, one wonders why the coverage was not extended to important missiles such as the Bristol Bloodhound, Armstrong Whitworth Seaslug, etc. Another strange omission is the lack of a mention in the Sputnik insert that this was the World's first satellite.

From the technical viewpoint, the book is sound and no glaring errors were spotted. The introduction titled "What it's all about" is excellent and most informative, and contains information on satellite trajectories often omitted from much larger and expensive books.

Summing up, if more details on the missiles covered had been given, and the more important non-U.S. missiles included, this book could have been a miniature missile encyclopedia. Alternatively, it should have been condensed into a cheaper simpler catalogue. If British readers want the latter, alternative books are available at a fraction of the cost of this U.S. book.

M. F. ALLWARD.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DYNAMICS ENGINEERS

to study tactics and performance of various weapons and space systems, and to prepare guidance and control systems design specifications. The senior engineers will contribute to, and interpret, overall strategic studies and initiate detailed work on them.

QUALIFICATIONS—Senior engineers: a degree or equivalent with 5-10 years' experience; knowledge of air-launched missiles and digital and analogue computers is desirable. Junior engineers will have some, but not all, of these qualifications.

SPACE TECHNOLOGIST

to study general problems of the exploitation of space. He will become experienced in all aspects of launching vehicles, missions, space probes and satellite equipment, and will initiate detailed studies of those applications which particularly relate to this country's interests.

QUALIFICATIONS—At least 10 years' relevant background in missiles, radar or electronics, enthusiasm for the future in space and knowledgeable about current activity in this field.